Logistics Management Institute

The Department of Defense's Flexible, Computer-Integrated Manufacturing Initiatives

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Executive Summary

DoD seeks to reduce the cost and time required to procure replacement parts. To do so, DoD must improve its inventory management and design engineering for all items, as well as its manufacturing engineering and production operations for items made in defense depots. Flexible, computer-integrated manufacturing (FCIM), as defined by DoD, "is the integration of equipment, software, communication, human resources, and business practices within an enterprise to rapidly manufacture, repair, and deliver items on demand, with continuous improvement in the processes." FCIM refers not to a single program or technology but rather to an amalgam of initiatives.

Virtually all activity in the FCIM initiatives has focused on inventory management and engineering. The Navy Rapid Acquisition of Manufactured Parts (RAMP) Program has developed hardware and software modules for improving manufacturing engineering and production management; other capabilities are under development. RAMP modules are operational in 12 Navy and Army facilities. The Army FCIM Program has focused on establishing electronic links between inventory management and design engineering sites and on strengthening the analytical capability of those sites. The Air Force Spare Parts Production and Reprocurement Support Program has taken a somewhat narrower focus, choosing to implement capabilities for converting product design to electronic format and for storing, retrieving, and updating that electronic data. The Joint Center for FCIM provided funds to the military services for myriad projects for reducing lead time and cost. Finally, some depots have modernized their shop-floor equipment by using depot capital investment funds or other, non-FCIM appropriations.

We found that, while the technology behind DoD's FCIM initiatives is sound, the business case supporting implementation at specific depots has not been well defined. Few data have been collected or published upon which to evaluate the return on investment or to prioritize future implementations. In addition, anticipated workloads at facilities using RAMP modules have not materialized. We recommend that depots implementing major manufacturing technology systems provide rigorous business justification for the investment.

The initiatives we examined focus on two specific commodities: small mechanical parts, and printed wiring assemblies. For these commodities, DoD has substantial excess depot machine capacity; we observed machine use to be between 10 percent and 50 percent of capacity. These observations are consistent with the overall maintenance depot capacity utilization of less than 50 percent that results from applying a commercial definition of capacity.

We looked to a commercial firm, Boeing, for part-supply strategies analogous to the DoD depots' manufacturing mission: providing long-term support for parts that are produced in small quantities and whose customer demand is uncertain. At Boeing's Emergent Manufacturing Facility, about 15 percent of capacity is devoted to "emergency" production of spares. This work is supplemented by producing spares for inventory and components for Boeing's aircraft assembly plants. Spare parts orders have priority, keeping responsiveness high. The supplemental production keeps utilization high and smoothes the production schedule. Boeing's practice provides a useful model for that depot capacity which DoD chooses to retain in-house to fill requirements when contractors cannot or will not meet its needs.

Boeing offers another practice that DoD could apply to parts that it buys from contractors. Boeing has defined eight families of spare parts that it purchases. Each family consists of from 200 to several thousand parts that share design and manufacturing features, and Boeing awards its entire requirement for parts in a given family to one or two suppliers. The combined volume makes Boeing an important customer to each supplier and helps to stabilize the supplier's workload. This concept is currently being explored by DLA in its On Demand Manufacturing program.

We were asked to examine whether depot manufacturing "cells" created by RAMP or other DoD programs could be relocated to other depots or to private-sector companies. We found that these programs have not created stand-alone manufacturing cells. While some depot manufacturing shops are physically separate from the broader depot operations, in almost every case those shops' information systems — such as for order entry, job scheduling, personnel, and accounting — are intimately entwined with the depot's business systems. We conclude that, because of the links between these shops and their host depots, moving the operations, as configured, to other locations would be impractical. While DoD could certainly reallocate its capacity (e.g., individual machine tools), moving an entire operation would involve significant reconfiguration and reinstallation of the associated control systems.

Technical product and process data in electronic format is the glue that binds the components of computer-integrated manufacturing together. Despite DoD's policy of acquiring access to technical data, there will always be circumstances in which complete technical data simply do not exist. When this occurs, DoD must develop technical data for replacement parts through reverse engineering or redesign. This activity must take place regardless of whether the part is then manufactured in a depot or by the private sector. Creating or updating technical data is currently done primarily by the government but could be contracted to private-sector design firms.

DoD supports a number of programs related to creating, using, and communicating digital technical data and should remain involved in setting and evaluating standards for digital technical data. A fundamental tenet of depot manufacturing is that commercial suppliers cannot or will not respond within cost or lead-time requirements. We recommend that DoD study the issue of contractors' reluctance to bid on parts and identify its root causes. One possible cause is incomplete or incompatible technical data.

In summary, three military-service programs and a number of broader initiatives are providing technology that DoD can use to procure replacement parts. Most of the effort is aimed at streamlining inventory management and engineering activity rather than at increasing production equipment capacity or capability. The technologies are sound, but, unfortunately, the military services have not done enough to understand where and in what order to implement them economically. Commercial strategies, such as those employed by Boeing, offer some alternatives that could be adapted by DoD.

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Acknowledgments

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CHAPTER 1

Background

PROBLEM STATEMENT

In the course of maintaining its weapon systems, DoD repairs existing component parts and procures replacement parts. Most replacement parts are procured from private-sector manufacturers, while the remainder are manufactured in DoD's own maintenance depots. In FY94, defense depots manufactured $380 million worth of replacement parts.[1] That figure represented 2 percent of Defense Business Operations Fund expenditures for depot maintenance activities, which were estimated at $13 billion.[1]

In addition to being a major cost to DoD, the time involved in manufacturing replacement parts has a direct impact on DoD's inventory levels and military readiness. Estimates of the average lead-time for procuring parts range from 300 days to more than 500 days. The military services have adopted a baseline procurement profile that consists of 200 days for administrative activities, 30 days for manufacturing planning, and 70 days for production (300 days in total).[2] A 1990 sampling by James H. Perry found that mean procurement lead times were even longer, ranging from 358 days for common consumables to 805 days for aviation parts.[3] The same study found that not only were private-sector lead times considerably shorter (typically 45 days to 365 days), but also the variance of lead times was considerably shorter. Lead-time uncertainty directly affects the amount of inventory that a supply system must carry to provide a given level of service. For a sampling of comparable aircraft parts, Perry found that DoD had more than twice as much invested in inventory as the private sector had, simply because of the Department's longer lead times. The challenges described by Perry continue to face DoD, which still seeks to reduce the cost and time required to procure replacement parts for its equipment.

Starting in 1986, several offices within DoD realized that lead-times and costs for the procurement of replacement parts lagged behind performance in the commercial sector. In addition, contractors were increasingly not responding to bid requests for certain old or low-demand parts. In reaction, the Navy initiated the Rapid Acquisition of Manufactured Parts (RAMP) program. In 1991, the Joint Logistics Commanders chartered the Joint Technical Coordinating Group on Flexible Computer Integrated Manufacturing (FCIM). In the same year, the Army established the Integrated Flexible Manufacturing Systems Program, later

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[1]Based on a March 1995 data extract from DoD's AP-MP(A)1397 depot maintenance production report for Fiscal Year 1994. The AP-MP(A)1397 report data base is maintained by the Defense Manpower Data Center in Arlington, Va.

renamed the Army FCIM Program, and the Air Force began the Spare Parts Production and Reprocurement Support (SPARES) program. These and other DoD manufacturing initiatives were started to facilitate the rapid procurement of replacement parts. Specifically, the RAMP and FCIM efforts set the goal of procuring in 30 days those parts sourced from DoD's internally operated maintenance activities.

The term "FCIM initiative" commonly refers to DoD programs, whether formal or informal, that have the objective of reducing procurement lead-times. As originally conceived, the DoD components would jointly develop technology and techniques under these manufacturing initiatives and then would install the resulting systems in their respective maintenance and manufacturing facilities. Given reductions in defense operations and restructuring of the maintenance depot system, the Deputy Under Secretary of Defense (Logistics), or DUSD(L), sought a strategic assessment of these initiatives and recommendations that might increase their net benefit to DoD. Specifically, DUSD(L) requested that the Logistics Management Institute (LMI)

- summarize the status of FCIM initiatives, including the technology, costs, and benefits that have been achieved to date;
- identify and analyze strategies for implementing FCIM technology in government depots and arsenals, giving consideration to the costs and benefits of that technology and to the changing work profile of those facilities; and
- identify and analyze strategies for contracting with private companies that yield similar benefits such as applying FCIM technology in government facilities.

Although we do discuss in this report the impact of DoD's FCIM initiatives on private-sector part suppliers, we mainly describe the status of the initiatives and analyze strategies for their implementation.

DEFINITION OF FLEXIBLE, COMPUTER-INTEGRATED MANUFACTURING

Flexible, computer-integrated manufacturing is a term coined by DoD. It is a composite of two terms, "flexible manufacturing" and "computer-integrated manufacturing," that are widely used in industry. Flexible manufacturing represents the ability to manufacture multiple parts, or families of parts, in small to moderate volumes, using the same collection of machines.[4] As used by industry, the term flexible manufacturing refers almost exclusively to collections of machines and their associated computer controls and material-handling equipment. Computer-integrated manufacturing (CIM)[2] represents the goal of linking, via computer, all the diverse activities in a manufacturing business: from the perception of product need, through design, marketing, production, and support. One of the most widely accepted descriptions of CIM is that of the Society of Manufacturing Engineers (SME). They identify five fundamental business activities included as part of CIM:

- General business management
- Product and process definition
- Manufacturing planning and control
- Factory automation
- Information resource management.

SME notes that, while CIM implies integrating all activities in a manufacturing business, in practice many companies have successfully integrated only some systems and few, if any, companies are totally integrated.

Combining the notions of flexible manufacturing and CIM, DoD developed the term "flexible, computer-integrated manufacturing." DoD defines FCIM as "the integration of equipment, software, communication, human resources, and business practices within an enterprise to rapidly manufacture, repair, and deliver items on demand, with continuing improvement to the processes."[5] Implied by DoD's addition of the word "flexible" to what otherwise closely parallels industry's definition of CIM is the notion that DoD's manufacturing business deals with a great variety of parts, usually made in small volumes.

DoD Manufacturing Sites

DoD's manufacturing facilities are located at maintenance depots and arsenals.[3] Tables 1-1 through 1-4 show DoD's manufacturing sites, arrayed by military service. We derived these lists from the domestic maintenance depots, as identified by JDMAG.[6] We have not included depots slated for closure by the 1993 Base Realignment and Closure Commission and have noted those facilities recommended for closure or realignment by the 1995 commission.[7] To the JDMAG's roster, we have added the Army arsenals at Rock Island and

[2]The acronym "CIM" is widely recognized in industry as meaning "computer-integrated manufacturing." That phrase predates and should not be confused with the altogether different meaning derived by DoD, "corporate information management."

[3]DoD's ammunition plants also possess manufacturing capability. The Joint Depot Maintenance Analysis Group (JDMAG), in defining maintenance depots, treats ammunition plants inconsistently, including those of the Navy but not those of the Army and Air Force. Because of their unique mission, we do not include ammunition plants in this study.

Watervliet, as they possess significant manufacturing capability and produce replacement parts in support of the weapons they manufacture. We have also added the Naval Air Warfare Center, Aircraft Division, in Indianapolis, which performs depot maintenance (including manufacturing) but is not on the JDMAG's roster. From the JDMAG's roster, we have eliminated the naval weapons stations, which are primarily ammunition depots. Our lists do not reflect manufacturing capability at lower levels of maintenance, at R&D sites, or with deployed units. In total, we list 30 facilities with a parts manufacturing capability.

Table 1-1.
Air Force Manufacturing Sites

Base	Commodities Maintained	State
Aerospace Maintenance and Regeneration Center	Aircraft, missiles	Arizona
Ogden Air Logistics Center	Ammunition, landing gear, tactical aircraft, strategic missiles	Utah
Oklahoma City Air Logistics Center	Strategic and support aircraft	Oklahoma
Sacramento Air Logistics Center[a]	Avionics and electronics, tactical and support aircraft	California
San Antonio Air Logistics Center[a]	Engines, support aircraft	Texas
Warner-Robins Air Logistics Center	Fixed-wing aircraft	Georgia

[a]Slated to be closed or realigned by the 1995 Base Realignment and Closure Commission.

Table 1-2.
Army Manufacturing Sites

Base	Commodities Maintained	State
Anniston Army Depot	Heavy combat vehicles, small arms	Alabama
Corpus Christi Army Depot	Rotary-wing aircraft	Texas
Letterkenny Army Depot[a]	Howitzers, tactical missiles	Pennsylvania
Red River Army Depot[a]	Light and medium combat vehicles	Texas
Rock Island Arsenal[b]	Howitzers, gun mounts	Illinois
Tobyhanna Army Depot	Communications, electronics	Pennsylvania
Watervliet Arsenal[b]	Cannons and guns	New York

[a]Slated to be closed or realigned by the 1995 Base Realignment and Closure Commission.
[b]Not technically a maintenance facility but included because of its engineering and manufacturing capability.

Table 1-3.
Marine Corps Manufacturing Sites

Base	Commodities Maintained	State
Marine Corps Logistics Base — Albany	Light track/tactical wheel vehicles	Georgia
Marine Corps Logistics Base — Barstow	Heavy track vehicles	California

Table 1-4.
Navy Manufacturing Sites

Base	Commodities Maintained	State
Naval Aviation Depot — Cherry Point	Fixed- and rotary-wing aircraft	North Carolina
Naval Aviation Depot — Jacksonville	Fixed-wing aircraft	Florida
Naval Aviation Depot — North Island	Fixed-wing aircraft	California
Long Beach Naval Shipyard[a]	Nonnuclear surface ships	California
Norfolk Naval Shipyard	Ships	Virginia
Pearl Harbor Naval Shipyard	Ships	Hawaii
Portsmouth Naval Shipyard	Submarines	New Hampshire
Puget Sound Naval Shipyard	Ships, submarines	Washington
Naval Air Warfare Center, Aircraft Division, Indianapolis[a]	Avionics, electronics systems	Indiana
Naval Electronics Systems Engineering Center, Portsmouth[a]	Electronics systems	New Hampshire
Naval Electronics Systems Engineering Center, San Diego	Test equipment, electronics systems, cryptographic equipment	California
Naval Ordnance Station, Crane Division[a]	Gun weapon systems, surface missile system launchers	Kentucky
Naval Surface Warfare Center, Indian Head Division	Electronics systems, night vision equipment, small arms	Indiana
Naval Surface Warfare Center, Crane Division	Electronic warfare	Indiana
Naval Undersea Warfare Center, Keyport Division[a]	Undersea weapons, targets, countermeasure systems	Washington

[a]Slated to be closed or realigned by the 1995 Base Realignment and Closure Commission.

The presence of manufacturing capability in maintenance depots serves several purposes. First and foremost, at least unofficially, is the practical necessity of having basic fabrication capability close to the repair activity. Every day, countless instances of bending, straightening, welding, and grinding — all manufacturing operations — take place on an ad hoc basis in support of weapon systems repair. More officially, depot manufacturing capability exists to do that work that the private sector spurns in peacetime and to provide a buffer until the private sector can mobilize in wartime. In addition to direct support of the repair process, peacetime production of replacement parts occurs because the private sector has not responded to a bid request or the private sector cannot respond within acceptable cost, schedule, or performance terms.

DoD's maintenance depots are principally known for their overhaul, repair, and manufacturing capabilities. Maintenance in general, and replacement parts procurement in particular, encompasses far more than just shop-floor production. Inventory management — deciding when, how much, and from whom to buy — is performed by the Defense Logistics Agency (DLA) for most consumables (approximately 3.5 million items); by military service commands, for most reparables (about 1 million items); and by depot material managers, for tooling and local material needs.[4] Although sometimes design and manufacturing engineering are located together, design engineering (in this case, design validation, reverse engineering, or redesign) is performed by military service commands, but manufacturing engineering (converting product specifications to process specifications) is performed by the maintenance depots. Production capabilities are spread throughout DoD's 30 maintenance depots and arsenals. Depot production is limited, by policy and in practice, to items for which a commercial source cannot meet DoD's cost, schedule, or technical requirements.

Each military service has organized its inventory, engineering, and manufacturing operations somewhat differently. In the Air Force, inventory management, engineering, and maintenance (including manufacturing) are located together at Air Logistics Centers. In the Army, inventory management and engineering functions are located at the major commands: Armament, Munitions, and Chemical Command; Aviation and Troop Command; Communications-Electronics Command; Missile Command; and Tank Automotive Command. Maintenance is based separately at Army depots. In the Navy, inventory management is centered at systems commands: the Naval Air Systems Command, the Naval Sea Systems Command, the Space and Naval Warfare Systems Command, and the Naval Supply Systems Command. Engineering to correct deficiencies in existing systems is collocated with maintenance at depots and shipyards. Engineering for upgrades is typically done at the Navy's warfare centers.

The military services and DLA share responsibility for managing inventories and for procuring parts and assemblies. The military services' inventory managers oversee reparable items and some consumable items. DLA, through its Supply Centers, manages the inventory and procurement of most consumable items. DLA now manages 3.5 million of 4.5 million supply items used by the military services. The Agency's budget is about $20 billion, with 50 percent allocated to the Defense Fuel Supply Center; 25 percent to the Defense Personnel Support Center; and 25 percent to the Defense Construction, Electronics,

[4]While the number of items managed by DoD is indeed large, a single large commercial firm, The Boeing Company, manages about the same number (4.6 million) in its on-line data base.

General, and Industrial Supply Centers. DLA places most of its procurements with the private sector. In FY93, DLA placed only approximately 50 orders, valued at about $5 million, with government depots.[8]

SCOPE OF STUDY

The manufacturing operations we studied closely paralleled those targeted by the RAMP program: small-part machining and printed wiring assembly. While important, these operations represent only a portion of depots' overall activities. The metal-part machining and printed-wiring assembly shops at the depots we visited typically were staffed by between 50 and 100 people, including engineering support, while the depots where they are located have total complements of 3,000 to 4,000 people.[5] In addition to disassembly, diagnosis, and assembly commonly associated with the repair process, the remaining people are engaged in a wide variety of manufacturing tasks that we did not study. These include sheet-metal work, welding, heat treating, and device-level electronic work.

REPORT ORGANIZATION

In Chapter 2, we discuss the major defense initiatives in FCIM, some important related programs, and analogous efforts at two private companies. In Chapter 3, we analyze our findings and present recommendations for advancing FCIM in a way that balances the technical opportunity with fiscal efficiency. Finally, we present supporting information in a series of appendixes.

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[5]See Appendix A for case studies of the depots we visited.

CHAPTER 2

Description of Initiatives

THE NAVY'S RAPID ACQUISITION OF MANUFACTURED PARTS PROGRAM

Background

The U.S. Navy, as well as the other military services, has had problems in providing spare and repair parts for increasingly complex and varied weapon systems and other field systems. These problems stem from rapid changes in technology, a diversity of fielded systems, diminishing domestic manufacturing sources, and lack of technical data. This has resulted in increasing procurement lead-times, high part costs, excessive inventories, and difficulties in finding sources for parts.

The Naval Supply Systems Command (NAVSUP) realized that the new techniques and technologies coming to the forefront could be used to provide a "spare parts on demand" capability that would improve U.S. Navy logistics support. In 1986, NAVSUP began formulating the RAMP program to provide spare parts on demand to fulfill fleet and shore establishment needs.[1]

The RAMP program is a Navy logistics effort to infuse computer-integrated manufacturing (CIM) technology into the Navy logistics structure to reduce cost and procurement lead-times in the manufacturing of small quantities of high-quality parts. The objectives of the program are to define the acquisition process; to identify, evaluate, and select the best commercial software for assisting or automating each step of the acquisition process; and to fund the development of proprietary software that links the commercial packages into an integrated system.

The Navy contracts with Team SCRA in North Charleston, South Carolina, to develop and install RAMP technologies. Team SCRA is an organization led by prime contractor SCRA, with Grumman Data Systems, Arthur D. Little, SEACOR, and Battelle as subcontractors.

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[1]Throughout this section, information was provided by Mr. Jason Hirsh, U.S. Navy Program Manager for RAMP, and by Dr. John H. Bradham, RAMP Program Manager, Team SCRA (named after the South Carolina Research Authority). RAMP technical information and statistics were compiled from a letter, dated 19 January 1995, from Dr. Bradham to Eric Gentsch.

Team SCRA has developed and integrated a suite of software modules that has been installed at DoD facilities (principally maintenance depots) and is available commercially to private industry. A RAMP demonstration site has been developed at SCRA's facility (SCRA has invested $6 million to $8 million in computer systems and equipment to support its RAMP facility), and components of the RAMP family of products have been installed at various depots. Appendix A contains brief case studies of the depots we visited, including those with RAMP products.

RAMP System Architecture

RAMP is built around the concept of a "workcell," which consists of engineering software for design and process planning, production management control systems, and computer links to shop-floor equipment. As RAMP evolves, other functions, such as bidding and cost tracking, are being added to the workcell concept. Team SCRA's suite of RAMP products addresses two classes of workcells: small mechanical part (SMP) and printed wiring assembly (PWA). As we observed at defense depots, any given site can implement the portions of the workcell that suit their needs; they need not implement an entire workcell.

The two RAMP workcell types share a generic, modular, open architecture. This architecture is hierarchical in nature and, apart from shop-floor interfaces, is essentially the same for both SMP and PWA workcells. The architecture is based on modular computer components designed to assist or automate the tasks involved in the spares requisition process. The modules use a common relational database and are integrated via an Open Systems Interconnection network. SCRA's strategy in developing these modules was to select commercial products wherever available (e.g., Oracle for database functions, Pro/ENGINEER for computer-aided design [CAD]) and develop encapsulating shells to permit them to communicate with each other. In instances where SCRA felt commercial applications were inadequate, it developed proprietary applications itself.

The modularity in the architecture is designed to facilitate future upgrade, expansion, and modification of the software components as technology progresses. Team SCRA believes the flexible interfaces allow the use of a wide variety of software and hardware, thereby reducing the reliance on one vendor and giving greater freedom in choosing components that best fulfill the functional requirements. The Navy and Team SCRA originally envisioned that a RAMP system of hardware and software modules could be installed as a standalone system in a depot manufacturing environment. In practice, we found that RAMP modules indeed accommodate a wide variety of software and hardware, as each depot's implementation of RAMP is somewhat different. Also, we found that, virtually without exception, RAMP implementations do not stand alone but are closely linked with their supporting depot's information systems and are dependent upon them.

RAMP SMP Workcell

In developing RAMP, Team SCRA first defined the classes of products that its workcells would be capable of designing and producing. The SMP workcell can accommodate a discrete part that fits within a one-cubic-foot space and is machined from standard materials. The SMP workcell is designed to operate under the following conditions:

- The system workload is 15,000 parts per year per shift.
- The average production batch size is four units.
- Fifty percent of orders are repeats.[9]

RAMP PWA Workcell

Team SCRA designed the PWA workcell to accommodate printed circuit cards, typically no larger than 18 inches square, populated with discrete through-hole or surface-mount electronic components. The PWA workcell is designed to operate under the following conditions:

- The system workload is 15,000 parts per year per shift.
- The average production batch size is five units (later increased to 10 units).
- Fifty percent of orders are repeats.[9]

RAMP Activities and Software Modules

Table 2-1 lists the computer-based activities that make up a RAMP workcell, the product name, and whether the software was developed by SCRA. In some cases, SCRA has augmented commercial software with custom interfaces. Also, every implementation need not use the specific commercial products listed; SCRA can provide interfaces to other products.

Team SCRA has also developed a scaled-down version of RAMP designed for intermediate maintenance facilities and shipboard use. This version, "RAMP Lite," consists of CAD software, an engineering database, and a link to machine tools. A typical configuration would include several Intergraph workstations with Intergraph mechanical CAD software, Informix relational database, and SCRA-developed software. We briefly describe the major RAMP activities and modules in the following subsections.

Table 2-1.
RAMP Workcell Activities and Software Products

Activity	Product name	SCRA developed?
RAMP top-level control	RAMP Order Manager Oracle database	Yes No
Computer-aided design	Pro/ENGINEER	No
Digital product data generation	PDTrans — Mechanical PDTrans — Electrical	Yes Yes
Process planning	ICAD/MetCAPP or ITI MultiCAPP (macro); Computervision CADDS 5 or Intergraph CAD (micro); MEPlans (integrates macro and micro) GPPE (generative)	No No No No Yes Yes
Production scheduling and inventory control (P&IC)	P&IC	Yes
Manufacturing cell control and quality assurance (MCC&QA)	Consilium Workstream and, for SMP sites, Cincinnati Milacron TMS200 MCC&QA	No Yes
Shop-floor workstation control interfaces	Fastech Cellworks and Workstation Control	No Yes
Generation of request for quotes	BIDQuest	Yes
Generation of bids	BIDPrep	Yes
Accounting	ABCosTrac	Yes

RAMP Top-Level Control

The processing of orders through the system is controlled by the RAMP Order Manager (ROM). The ROM controls each job as it is processed by the functional components and contains the current status of every order.

Digital Product Data Generation

PDTrans — Mechanical creates a digital technical data package for new mechanical parts designs. This system, with SCRA-developed code linking Parametric Technology Corporation's Pro/ENGINEER CAD system and Oracle's database management system, runs on Sun SPARC workstations. The software takes as input data generated by CAD software or input from blueprints and aperture cards. Output is available in a number of formats, including ISO 10303, *Standard for the Exchange of Product Model Data;* ANSI/SAE J1881-AUG88, *Initial Graphics Exchange Specification (IGES);* and raster.[2]

PDTrans — Electrical creates a digital technical data package for PWAs from existing product designs captured from reverse engineering or legacy data (i.e., schematic diagrams, aperture cards, and digital files). This system is built around Intergraph CAD software running on Intergraph workstations. Output formats include IGES; ANSI/IPC D-350D-1992, *Printed Board Description in Digital Form;* ANSI/EIA 548-1988, *Electronic Design Interchange Format Version 200;* raster, and text.[3] The data created by PDTrans — Mechanical and PDTrans — Electrical form the basis for subsequent process planning and scheduling activities.

Process Planning

Process planning in RAMP requires two steps: macro and micro. RAMP's MEPlans software module helps perform macro process planning for bid generation (creating estimates of cost and schedule). It also provides input to the subsequent micro process planning for generation of tool paths, machine setups, machine operation instructions, and fixture setups. The level of micro process planning assistance is dependent on the quality of the technical data in digital format.

For SMPs, MEPlans uses product data formatted in accordance with ISO 10303, Application Protocol 224, *Mechanical Parts Definition for Product Planning Using Form Features.* MEPlans also can function with less robust geometric data formatted in accordance with ISO 10303, Application Protocol 203, *Configuration-Controlled Design.* The knowledge-based process planning system is driven by a set of rules and data that model shop processes, equipment, and the knowledge of an expert machining process planner.[4]

Macro process planning for SMPs is implemented using SCRA-developed code supplementing an ICAD/MetCAPP or an ITI MultiCAPP system. Micro process planning uses a Computervision CADDS 5 CAD system or an Intergraph CAD system. SCRA markets process-planning products commercially under the name MEPlans and GPPE (Generative Process Planning Environment).

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[2]ISO is the International Organization for Standardization; ANSI is the American National Standards Institute; and SAE is the Society of Automotive Engineers. Product data standards are discussed further later in this chapter.

[3]IPC is the Institute for Interconnecting and Packaging Electronic Circuits; and EIA is the Electronic Industries Association.

[4]RAMP does not support the following processes: heat treatment, grinding, sheet metal forming, flame cutting, welding, plating, painting, lapping, and honing. RAMP can, however, accommodate these processes by handling them as vendor operations.

PWA process-planning software performs functions similar to the SMP software. Major commercial software packages included in this module are Computervision's CADDS 5 CAD package for electrical and mechanical parts, LISP programming language, Oracle database software, and Solarsis software.

Production Scheduling and Inventory Control

RAMP production scheduling and inventory control (P&IC) is based on finite-capacity, forward-scheduling techniques. A pull-type system will control orders through the shop in both SMP and PWA workcells. Under this system, demands for products downstream in the manufacturing flow cause the release of related component parts upstream. This contrasts to push-type systems, where production orders are released based on forecasts, regardless of whether there is a true need or whether manufacturing capacity is available.

Manufacturing Cell Control and Quality Assurance

The manufacturing cell control and quality assurance (MCC&QA) module receives the micro process plans and workstation instructions from P&IC and manages activities on the shop-floor, including work-order release, maintenance, and quality-data collection. Following completion of manufacturing and inspection, MCC&QA provides packaging instructions. This module is based on Consilium's Workstream software and, for SMP workcells, Cincinnati Milacron's TMS 2000 workcell controller package. MCC&QA requires VAX 4000 mainframe hardware.

Shop-Floor Workstation Control Interfaces

In a RAMP workcell, computers reside at each workstation (e.g., machine center, assembly station, and inspection station) and serve as an interface between MCC&QA and the machine controller[5] or the workcell technician at a manual work position. The workstation controller receives data and instructions from MCC&QA. For example, the workstation controller passes numerical control (NC) programs to machine controllers and displays setup images and special operator instructions. The workstation controller also collects quality and status information for transmission to MCC&QA. The workstation controllers are either microcomputers or Sunsparc(LX) workstations running Fastech Cellworks software.

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[5]The machine controller, which commands automated machine movements, is a separate computer from the workstation controller, which stores and delivers instructions from higher-level computers.

RAMP Installation Costs

SMP Workcell Installation

In Table 2-2, we summarize the initial costs of the hardware, software, training, and annual maintenance and licensing agreement fees necessary to support a typical RAMP facility. For the SMP RAMP workcell, the costs are based on a typical facility with 5 workstations for creating and editing the designs, 1 for macro process planning, 5 for micro process planning, and 23 shop-floor workstations that require workstation controllers.[6] Note that these are the incremental costs that apply to government installations. Because the government funded development of RAMP, SCRA-developed code is free. For commercial installations, SCRA would undoubtedly charge a fee.

Table 2-2.
SMP Workcell Costs
(dollars)

Module	Hardware	Software	Training	MLA
RAMP top-level control	120,000	77,710	31,530	41,250
CAD, PDTrans — Mechanical (5 workstations)	105,000	207,000	93,125	44,625
Process planning (1 workstation macro, 5 workstations micro)	252,000	430,400	121,290	76,100
P&IC	88,000	141,660	3,100	34,458
MCC&QA	125,000	479,710	15,700	98,800
Shop-floor interface (23 stations)	305,900	288,075	117,760	69,575
BIDQuest	7,600	6,600	12,040	0
BIDPrep	3,500	1,400	8,120	0
ABCosTrac	18,500	19,975	17,920	7,445
Totals	1,025,500	1,652,530	420,585	372,253

Source: Letter from Dr. John H. Bradham, RAMP Program Manager, SCRA, to Eric L. Gentsch, 19 January 1995.

Note: Hardware, software, and training costs are one time. MLA reflects annual maintenance and licensing agreement costs.

The total investment in computer hardware, software, and training for this typical RAMP SMP workcell is approximately $3,099,000, with annual fees of approximately $372,000. Further investment is required to install the systems (including networking hardware) and load the data. For installations with

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[6]This configuration reflects the Charleston Naval Shipyard, which Team SCRA cited as being typical. Shop-floor workstations implemented at other RAMP SMP sites include Anniston (22), Cherry Point SMP (10), and Cherry Point Blade and Vane (25).

well-defined engineering data in electronic form (e.g., IGES drawings of individual tools), data loading will require a minimum of 100 hours per machine tool. New facilities or processing equipment would require additional funding. The operation of a typical RAMP SMP workcell would require a staff of at least nine administrators and technicians in addition to the number of manufacturing engineers and machine-tool operators required to meet facility throughput requirements. A facility of this size should have production capacity of about 15,000 parts per year per shift.

PWA WORKCELL INSTALLATION

In Table 2-3, we summarize initial hardware, software, and training costs for each of the RAMP modules provided by SCRA for a typical PWA workcell with 3 workstations for creating and editing the PWA designs, 1 for macro process planning, 3 for micro process planning, and 12 shop-floor workstations.[7] Also included is the annual maintenance and licensing fee. As with the SMP workcell, these are the incremental costs that apply to government installations. Because the government funded development of RAMP, SCRA-developed code is free.

Table 2-3.
PWA Workcell Costs
(dollars)

Module	Hardware	Software	Training	MLA
RAMP top-level control	120,000	77,710	31,530	41,250
CAD, PDTrans — Electrical (3 workstations)	396,500	328,000	60,920	113,800
Process planning (macro: 1 workstation; micro: 3 workstations)	86,000	261,670	42,730	48,075
P&IC	88,000	141,660	3,100	34,458
MCC&QA	125,000	439,710	12,900	93,800
Shop-floor interface (12 workstations)	95,600	150,300	61,440	36,300
BIDQuest	7,600	6,600	12,040	0
BIDPrep	3,500	1,400	8,120	0
ABCosTrac	18,500	19,975	17,920	7,445
Totals	940,700	1,427,025	250,700	375,128

Source: Letter from Dr. John H. Bradham, RAMP Program Manager, SCRA, to Eric L. Gentsch, 19 January 1995.

Note: Hardware, software, and training costs are one time. MLA reflects annual maintenance and licensing agreement costs.

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[7]The number of shop-floor workstations initially installed at RAMP PWA sites include 11 at Indianapolis and 12 at Tobyhanna.

The total investment in computer hardware, software, and training for this typical RAMP PWA workcell is approximately $2,618,000, with annual maintenance and licensing fees of approximately $375,000. SCRA estimates that a workcell of this configuration with appropriate processing equipment would be capable of producing approximately 15,000 parts per year per shift.

RAMP Implementation in DoD

Table 2-4 lists the DoD sites where RAMP modules have been installed. Team SCRA has also installed RAMP products at a Federal Aviation Administration logistics center and is seeking commercial customers.

Table 2-4.
RAMP Sites by Workcell Type

Site	SMP	PWA	Inventory control point	Other
Aviation Supply Office, Philadelphia, Pa.			X	
Naval Air Warfare Center, Aircraft Division, Indianapolis, Ind.		X		
Naval Surface Warfare Center, Crane Division, Ind.		X		
Naval Surface Warfare Center, Louisville, Ky.	X			
Naval Undersea Warfare Center, Keyport, Wash.				X
Ship's Parts Control Center, Mechanicsburg, Pa.			X	
Tobyhanna Army Depot, Tobyhanna, Pa.		X		
U.S. Army Rock Island Arsenal, Rock Island, Ill.	X			
U.S.S. *Emory S. Land* (home port at Norfolk, Va.)	X (RAMP Lite)			
Naval Aviation Depot, Cherry Point, N.C.	X			X (blade and vane repair)
Charleston Naval Shipyard, Charleston, S.C.	X			
Trident Refit Facility, King's Bay, Ga.	X (RAMP Lite)			
Anniston Army Depot, Anniston, Ala.	X			
Sacramento Air Logistics Center, Sacramento, Cal.		X		

In Table 2-5, we list the RAMP modules in use at each facility. All sites except inventory control points, have some CAD capability; therefore, we have omitted that column from the table. In addition, note that the specific hardware, software, and even software version for any given module varies from site to site. Therefore, for example, while the Cherry Point and Anniston SMP workcells look similar from a listing of modules, their actual configurations are quite different. Team SCRA maintains a customer support department to manage configuration differences between the sites.

THE ARMY FCIM PROGRAM

Overview

In 1991, the Commanding General of the Army Materiel Command chartered the Integrated Flexible Manufacturing Systems Program. In 1992, that program became the Army FCIM Program. Based at Rock Island Arsenal's Industrial Engineering Activity, the goal of the Army FCIM Program is to supply replacement parts within 30 working days of identification of need.[8] That lead-time target is divided into 5 days from identification of item need until award, and 25 days from award until delivery of the completed product.[10]

The Army defines FCIM the same as DoD does: "the integration of equipment, software, communications, human resources, and business practices within an enterprise to rapidly manufacture, repair, and deliver items on demand, with continuous improvements in the processes."[5] The broad goals of the Army FCIM Program are better creation, revision, and interchange of information, with emphasis on links between design and manufacturing.

The impetus for the program was long lead-times. At the outset, the typical time from need identification until delivery was 500 days: 230 days administrative lead-time, 200 days manufacturing planning lead-time, and 70 days manufacturing lead-time.[2] A study of a sample of aircraft engine parts used by DoD and commercial airlines found DoD's average lead-time to be more than four times longer: 436 days, compared with 94 days. Similarly, DoD's average inventory investment was more than twice the commercial firms'.[2]

The Army's FCIM Program is aimed at parts for which private industry is not responsive.[11] For these items, the Army is trying to move from "just-in-case" stockage of parts to "just-in-time" production. The parts targeted by the program represent a small percentage (1 to 2 percent) of Army needs, but are typically critical to readiness.[2]

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Table 2-5.
Implementation of RAMP Modules by Site

Site	RAMP top-level control	PDTrans — Mechanical	PDTrans — Electrical	Process Planning	P&IC
Aviation Supply Office					
Naval Air Warfare Center, Aircraft Division, Indianapolis	X		X	X	X
Naval Surface Warfare Center, Crane Division			X		
Naval Surface Warfare Center, Louisville		X		X	
Naval Undersea Warfare Center					
Ship's Parts Control Center					
Tobyhanna Army Depot	X			X	X
U.S. Army Rock Island Arsenal		X		X	
U.S.S. *Emory S. Land*					
Naval Aviation Depot, Cherry Point	X				X
Charleston Naval Shipyard	X			X	X
Trident Refit Facility, King's Bay					
Anniston Army Depot	X			X	X
Sacramento Air Logistics Center	(According to SCRA, Sacramento has insta				

(2)

P&IC	Workcell control	Workstation control	ABCosTrac	BIDQuest	BIDPrep	RAMP Lite
				X		
X		X				
					X	
				X		
X		X				
					X	X
X		X	X		X	
X	X	X				
					X	X
X	X	X			X	

Sacramento has installed a RAMP "printed wiring board data capture system.")

THE MODULE CONCEPT

The term "module," as used by the Army, refers to a theoretical organization that cuts across formal DoD boundaries to supply a category of parts. A module consists of inventory-management, configuration-management (engineering), and manufacturing sites.[12]

Inventory management sites forecast demand, identify requirements for parts, request bids, and manage procurements. Some inventory-management sites are run by DLA; others, by the military services. Engineering sites manage and distribute the product data necessary to bid and manufacture a part. They also perform reverse engineering and redesign. Reverse engineering is developing a complete technical data package for an existing item by using a combination of existing data and engineering analysis. Redesign is modifying an existing design to create a functional equivalent while incorporating design or manufacturing improvements.[8] Engineering sites are run by the military services. Manufacturing sites prepare bids, perform manufacturing engineering, and make parts. Manufacturing sites, located at maintenance depots, are also run by the military services but do not have to belong to the same service engineering the part being made.[10]

The Army FCIM Program comprises two modules: an electronics module and a mechanical module. The Communications and Electronics Command (CECOM) manages the electronics module and focuses on circuit-card assemblies. Tobyhanna Army Depot is the primary government manufacturing site for the electronics module. The Armament, Munitions, and Chemical Command manages a mechanical module that involves metal parts machined from mill stock, castings, and forgings. Anniston Army Depot, Rock Island Arsenal, and Watervliet Arsenal are the manufacturing sites for the mechanical module.[12]

FCIM includes both process improvements and new capabilities. As an example of process improvement, Rock Island and Anniston Arsenals have eliminated unnecessary steps and redundant approvals from their estimating procedures. A new capability that the Army has undertaken is to integrate, through electronic networks, inventory management, configuration management, and manufacturing sites. Data to be integrated include requests for quotes, bids, invoices, technical data packages (including drawings), engineering change proposals, and NC code.[13] As part of the electronics module, CECOM and Tobyhanna can now exchange engineering drawing files electronically through the Defense Data Network. In the future, the link will include bidding, a Joint Engineering Data Management and Information Control System (JEDMICS) interface, and CAD conferencing.[13]

THE BUSINESS PLAN

The Army developed a business plan for its FCIM modules that describes the expected workload, costs, and benefits of the program.[2] For the electronics module, the Army examined a total of 439,503 items managed by both the Army and DLA. Of those, 16,256 were identified as candidates for depot manufacture, of which 4,514 had been demanded recently.[8] Of the items recently demanded, only 59 were managed by DLA (or the Government Services Administration); the rest were managed by CECOM, the Missile Command, or the Electronics Materiel Readiness Agency. Similarly, for the mechanical module, the Army evaluated 58,808 parts and found 4,212 candidates for depot manufacture. Of the candidates, 1,142 had been recently demanded.

Targeted production volume for the electronics module was 3,000 orders per year, with an average lot size of five. Targeted production volume for the mechanical module was 5,000 orders per year, with an average lot size of three.[2]

On the basis of these workload projections and a technical plan, the Army planned to obtain funding for nonrecurring investment from the Production Base Support portion of Army procurement appropriations. Operational costs were to be funded from the Army Stock Fund.

In implementing its module concept, the Army anticipated the requirement for shorter lead-times, improved resource management, increased operational control, improved quality, better documentation, reduced inventory and storage, and reduced labor. It analyzed the cost of using the module approach, assuming a volume of 15,000 parts per year over nine years. The Army projected that, by using the electronics module, annual operating costs would drop from $29 million to $17 million. The proposed work had 1992 present values of $10 million for costs and $62 million for savings. The Army projected a return on investment of more than 100 percent. By using the mechanical module, the Army anticipated that annual operating costs would drop from $26 million to $23 million. That proposal had 1992 present values of $7 million for costs and $19 million for savings, giving a projected return on investment 40 percent.[2]

Between FY91 and FY93, the Army spent $65 million to implement its module approach. As shown in Table 2-6, 84 percent was funded by Army appropriations; the remainder was funded by the Joint Center for FCIM. A retrospective assessment of actual return on investment is not available.

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[8]In its business plan, however, the Army did not completely describe its criteria for determining candidates for depot manufacture, nor what constitutes "recent demand."

Table 2-6.
Funding for the Army's FCIM Program (thousands of dollars)

Funding source	FY91	FY92	FY93	FY94	Totals
Joint Center for FCIM	N/A	1,123	7,792	0	8,915
Army — Production Base Support Appropriation	7,900	24,458	22,861	1,000	56,219
Totals	7,900	25,581	30,653	1,000	65,134

Source: "Army Flexible Computer Integrated Manufacturing (FCIM) Overview," briefing charts dated 2 March 1995, presented by Stephen A. McGlone.

N/A = Not Applicable.

The Electronics Module

As an example of the activities undertaken in the module concept, we describe the electronics module. Participants in the Army electronics module are

- CECOM, which acts as module manager and provides inventory management and engineering;
- Army Research Laboratory, which provides microcircuit engineering support;
- Tobyhanna Army Depot, which performs manufacturing engineering and production; and
- Computer Systems Development Corporation, which provides systems support.[11]

The electronics module concept also includes links to other government inventory control sites, such as the Defense Electronics Supply Center (DESC), and to other engineering and manufacturing sites.[11] For example, when CECOM identifies a requirement for depot manufacturing, it sends a request for quotations to each of three sites capable of bidding: Tobyhanna Army Depot, the Naval Air Warfare Center at Indianapolis, and the Air Force's Sacramento Air Logistics Center.[8]

CECOM manages between 70 percent and 80 percent of Army electronics, working at the board level and above.[11] CECOM faces two major challenges in procuring and maintaining replacement parts. The first challenge is that many existing parts' technical data consist of paper drawings or raster images, with little functionality data. More information is required to manufacture electronics than for mechanical items. Both share a need for physical geometry and material characteristics, but electronics specifications must also include data on functionality. Because it has so many old master patterns (40,000) and because converting to electronic format (including adding functional data) is expensive, CECOM is converting the patterns as the need arises, at the rate of several hundred per year.[11] CECOM also noted that, because of the complexity of the data requirements for electronics, the development of electronics application protocols under ISO 10303, *Standard for the Exchange of Product Model Data*, will lag behind that of mechanical protocols.[9]

The second major challenge facing CECOM is that many current product specifications reference a hodgepodge of test equipment and procedures used by the original manufacturer. These test specifications are becoming obsolete as electronics technology advances, which is important because testing is a major factor in electronics manufacturing.[11]

To deal with these challenges, investment in the electronics module has centered on creating an "electronic design network." This network includes upgrading and linking the metropolitan area networks at CECOM (in Fort Monmouth, New Jersey) and at Tobyhanna. It also includes methods for transmitting engineering data files and the development of software to assist reverse engineering and redesign.[11]

CECOM has applied electronics module improvements to items within the Satellite Communications (SATCOM) Branch and to the PRC-126 hand-held radio. SATCOM has 15 item managers responsible for a total of 6,000 parts. Since March 1993, these managers have directed 70 items, worth $10 million, for government manufacture because private industry did not respond or submitted excessive bids. For those items, CECOM reports several benefits resulting from its electronics module developments: administrative lead-time went from 8 through 12 months to 0.25 through 3 months and production lead-time shrank from 10 through 16 months to 3 through 8 months. CECOM attributes $3.8 million in savings to reducing inventory, and also says that unit production costs are lower than what the private sector would have provided. For example, for National Stock Number (NSN) 5998-01-182-9089, *Circuit Card Assembly*, CECOM cites a government unit production cost of $3,165 for a quantity of 20 (the Parts-Master database lists the Army as the current manufacturer, with a unit price of $6,671).[11] The previous buy, from the private sector, was in 1986, when Harris Corporation charged a unit price of $10,715 for a quantity of 4.[14]

The PRC-126 hand-held radio was originally purchased as a commercial, off-the-shelf item. The private sector price for replacement PRC-126 circuit boards has risen from $100 at the time of manufacture to $1,000 today. The modules' maintenance drawings are marked "not for reprocurement," and the contractor wants $5.3 million for a complete data package. As an alternative, CECOM is redesigning the boards at an estimated cost of $1.3 million.[11]

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[9]The term "application protocol" refers to digital product standards that are listed under the umbrella standard ISO 10303.

Several defense business procedures make it difficult for DLA and CECOM item managers to direct manufacturing work to maintenance depots. When government item managers procure items from government depots, it is the exception rather than the rule and takes extra work.

DESC, for example, will not procure an item from a government depot unless the private sector cannot offer reasonable prices, acceptable schedules, or technically acceptable terms.[8] Although DLA's Standard Automated Material Management System (SAMMS) does maintain a code (routing code "F") that identifies items to be made in government depots, solicitations for depots must be processed outside the normal information system. The DLA Pre-Awards Contract System cannot handle orders for government depots, as it automatically creates a solicitation with Federal Acquisition Regulation clauses that do not apply to the depots.[8]

At CECOM, identifying repeat parts to be made in depots is difficult. Procurement history for orders made in government depots is not kept in the Army's Commodity Command Standard System, and CECOM maintains a stand-alone computer to record that information. When an item is required, CECOM personnel must manually consult this file to determine if the item is to be made in a government depot. Also, tracking of depot orders (in process and completed) must be done manually.[8]

THE AIR FORCE SPARE PARTS PRODUCTION AND REPROCUREMENT SUPPORT PROGRAM

Background

The Spare Parts Production and Reprocurement Support (SPARES) program is an effort to convert product designs to electronic format and to store, retrieve, and update those electronic data. The program is also implementing software to speed the development of NC code for landing gear component repair.

SPARES was started in 1991 and is funded by the Air Force Manufacturing Technology Directorate.[15] The implementation site is the Ogden Air Logistics Center (OO-ALC) at Hill Air Force Base, Utah. Early efforts modeled the management of technical data to support the procurement of spare parts from private-sector suppliers and from DoD manufacturing sites. Activity-based costing was also performed to assist the OO-ALC in identifying their most costly and time-consuming activities that hindered the rapid procurement of spares parts. Examination of the process-modeling and activity-based costing activities (and the annual labor hours spent in support of these activities) revealed to the SPARES team that new technology would have the greatest impact on the reprocurement process if focused on activities that manage technical data and that affect all spare parts regardless of manufacturing source.

At OO-ALC, reducing the cycle time for technical data management has the greatest impact on reducing the cycle time for spare-part reprocurement. The SPARES Program, therefore, focuses on technical-data management activities that take place upstream of the generation of manufacturing data.

The Elements of the SPARES Program

The SPARES Program consists of the following elements:

- Electronic storage and retrieval of technical data
- Workflow management system
- Feature-based manufacturing engineering.

Each element is discussed in the following subsections.

ELECTRONIC STORAGE AND RETRIEVAL OF TECHNICAL DATA

The Engineering Data Computer Assisted Retrieval System (EDCARS) is the official Air Force repository for data on configuration-controlled weapon systems. These data are raster images on a proprietary AT&T system that must be accessed through specific EDCARS terminals and printers located throughout the OO-ALC. Much of the technical data needed for spare-part procurement, however, are stored outside EDCARS, as

- technical orders,
- screening forms,
- correspondence with vendors,
- engineering change orders,
- manufacturing process instructions,
- applicable military specifications,
- first production article data, and
- product-history data.

These non-EDCARS data are typically on paper and filed by NSN only. The SPARES Program is converting these non-EDCARS data into electronic form. The resulting system that performs these conversions also offers file management and full text search capabilities. A user can then search the entire contents of the data repository (containing drawings, correspondence, screening results, and manufacturing processes) for key words without having to know the NSN. The resulting data and access tools are made available to the OO-ALC computer networks and are thus accessible by any prospective user.

Workflow Management System

Many OO-ALC processes for managing technical data are paper intensive and require routing across several organizations. These processes add time to the part-reprocurement cycle. The first workflow being implemented under the SPARES Program is the processing of the Air Force's Form 196. Form 196 is a catch-all for answering questions from vendors who are considering bidding on the manufacture of spare parts. The quantity and dollar value of spare parts being reprocured is decreasing because of downsizing and budget cutbacks; therefore, the number of vendors bidding on the jobs is increasing and that number includes new vendors inexperienced with DoD. The workload of responding to bidder's questions is increasing and bogging down the procurement process. Presently, OO-ALC processes a Form 196 in 7 to 14 days, on average. The target set by the procurement office is 5 days. The time Form 196 spends in the base mail system alone averages nearly 5 days, leaving no time for the value-added activities related to answering the bidder's questions. Thus, electronically routing and tracking Form 196, rather than using the current paper process, would minimize the time lost at the organizational interfaces. A SPARES computer module has a workflow management tool that provides electronic access to all data repositories necessary to process Form 196. These data repositories include

- *legacy systems* — older electronic mainframe systems that maintain data in an electronic format;
- *local electronic repositories* — data, such as engineering drawings made at OO-ALC, that exist in native CAD formats; and
- *paper data repositories* — data, such as the Master File Folders, that are being converted to and maintained in an electronic format by the SPARES program.

The SPARES system provides access from the user's desktop computer to all data needed to perform the work assigned to the user. SPARES is not absorbing the vast legacy systems in existence at OO-ALC but rather is using modern electronic communications protocols to easily access these systems. However, one of the biggest current hurdles to widespread use of the SPARES system is the limited ability of the local-area networks at OO-ALC to handle electronic traffic.

Feature-Based Manufacturing Engineering

OO-ALC repairs and overhauls landing gear for all Air Force aircraft. Two major families of landing gear parts are bushings (single and double flanged, with and without chamfers and oil holes) and spindles. The overhaul process — which includes rezoning, replating, and rebuilding — requires new bushings and spindles to be made to specific dimensions and tolerances for a particular overhaul.

Programming the NC machines to make these repairs caused delays in the repair line. The SPARES Feature-Based Manufacturing Center software reduces these delays. The software uses a front-end driver for programming several NC lathe machines using a PC-based graphical user interface. The user specifies material and dimensions for bushings or spindles, and the system automatically generates the NC code for the manufacture of the part. In some cases this has reduced NC programming time from 10 hours down to 1 hour. The software has been used to manufacture more than 1,000 parts to date. Its use expanding to include other machine tools and more features.[16]

THE JOINT CENTER FOR FCIM

Background

In 1991 the Joint Logistics Commanders chartered the Joint Center for FCIM and the Joint Center for Continuous Acquisition and Life-Cycle Support (CALS).[10] The purpose of the Joint Center for FCIM was to investigate ways to reduce cycle time and cost for replenishing spares through technology, changes in business processes, and removal of policy and regulatory barriers. The Joint Center was not chartered to make capital investments in depot equipment, but rather to improve the spares procurement process, from requirements determination, through engineering, and through manufacturing.[18] The Joint Center recommended an approach that first emphasized changing business processes to simplify the existing systems and then applied technology (e.g., RAMP) to automate and further improve the response of these simplified and leaner systems by overcoming business, cultural, and organizational barriers.[19]

Process Validation Enterprises

The focus of the Joint Center for FCIM was the entire spares supply chain, from manufacturing back to the item managers. Through conceptual

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[10]In 1994, those centers were merged into one, the Joint Center for Integrated Product Data Environment (IPDE). In this section, we discuss the goals and activities of what was the Joint Center for FCIM.[17] At the time of writing, the activities of the Joint Center for FCIM are unaffected by the formation of the Joint Center for IPDE. The very existence of the Joint Center for IPDE is in question, however, because of budget cutbacks. CALS is a DoD strategy for effectively creating, exchanging, and using digital data for weapon systems and equipment. CALS forms an umbrella for a number of military standards and specifications. More information on CALS can be obtained from the World Wide Web site at http://navysgml.dt.navy.mil/cals.html.

organizations known as process validation enterprises (PVEs), the Joint Center for FCIM conceptually linked various parties involved in the spares requisition cycle. A PVE is an experimental organization that cuts across formal organizational boundaries in DoD and ties together inventory managers (customer representatives), engineering activities (configuration control), and manufacturing facilities (producers) with the associated vendor base (suppliers of raw materials, components, and services).

Seven manufacturing sites (two each from the Army, Navy, and Air Force; one from the Marine Corps) were chosen along with their associated inventory item managers and engineering sites for selected parts. Both electronic- and mechanical-component manufacturing are represented by Air Force, Army, and Navy manufacturing sites, while the sole Marine Corps PVE is a manufacturing site for mechanical components. The 22 initial PVE participants are listed in Table 2-7.[11] Note that DLA sites are participating in inventory activities.

Table 2-7.
PVE Participants

Inventory	Engineering	Manufacturing
Army Armament, Munitions, and Chemical Command	Army Communications Electronics Command	Anniston Army Depot/Rock Island Arsenal
Naval Aviation Supply Office	Naval Air Warfare Center, Weapons Division, China Lake	Naval Air Warfare Center, Aircraft Division, Ind.
DLA Defense Construction Supply Center	Oklahoma City Air Logistics Center	Naval Surface Warfare Center, Crane Division, Louisville, Ky.
DLA Defense Electronics Supply Center	Warner-Robins Air Logistics Center	Marine Corps Logistics Base, Barstow
DLA Defense General Supply Center		Sacramento Air Logistics Center
DLA Defense Industrial Supply Center		Tobyhanna Army Depot
Ogden Air Logistics Center		Warner-Robins Air Logistics Center
Oklahoma City Air Logistics Center		
Tank Automotive Command		
Sacramento Air Logistics Center		
Warner-Robins Air Logistics Center		

Early FCIM studies showed that "above-the-shop-floor" (administrative and engineering) activities were responsible for most of the procurement lead-time for the high-cost, long-lead-time parts manufactured in government depots. As

[11]By 1994, the Joint Center for FCIM counted 50 sites making improvements under the FCIM banner.

a result, most FCIM efforts were focused on above-the-shop-floor activities, with special emphasis on converting product data to digital form. Further, because the Joint Center staff felt that the underlying FCIM concepts were broadly applicable, the scope of the initiative was extended beyond the small group of parts manufactured by DoD that were difficult to procure commercially to include all spares. The overall goal was to reduce the total procurement lead-time to 30 days for all parts.[19,20]

The changes resulting from this process were to be documented and disseminated to the military community. One of the widely accepted business practices that FCIM embraced was the empowerment of people at all levels in PVEs so that those people could initiate change. FCIM is thought to have provided a mechanism for disseminating new technology (not developed through FCIM) and an environment to encourage experimentation.

While working to reduce the time and cost of spares replenishment, the FCIM initiative also sought to institutionalize a systems approach to the improvement process (e.g., focus on total cost of replenishing spares rather than just on the unit cost of spares). We were told that the value of FCIM cannot be measured by improvements made to date — the true value of FCIM may be in the creation of an appropriate environment for change and technology adoption.

Funding

The Joint Center for FCIM received funding but did not conduct projects per se. Rather, the Joint Center allocated the funds to the military services, which performed the work under the conceptual umbrellas of FCIM and PVEs. Funding for the Joint Center for FCIM is shown Table 2-8.

Table 2-8.
Funding for the Joint Center for FCIM (thousands of dollars)

Fiscal year	Funding
1992	8,850
1993	13,900
1994	790
Total	23,540

The Joint Center provided a breakout of funded activities for 1992 and 1993. In those years, the Joint Center provided $21.5 million to 26 projects conducted by the military services and DLA.[20] Included in the list of projects is the Navy RAMP, the Army FCIM, and the Air Force SPARES programs. Almost all funded projects dealt with above-the-shop-floor process improvements and technologies. Beyond the three major military service FCIM Programs listed above, the Joint Center sponsored projects for

- PWA artwork layout,
- laser scanning for reverse engineering,
- CAD file translators,
- shop-floor control software,
- CAD integration with coordinate measuring machines,
- integrated circuit design methodologies,
- automated diagnostics for PWAs,
- a bid and quote system,
- modular fixtures, and
- CAD conferencing.

In many cases, Joint Center funding for these projects was augmented by military service funds from other appropriations.

OTHER RELATED INITIATIVES

Joint Engineering Data Management and Information Control System

JEDMICS will be the DoD standard repository for managing and controlling engineering data.[21] In response to a 1983 Secretary of Defense tasking to automate engineering data repositories, the Navy initiated the Engineering Data Management Information and Control System (EDMICS) program. Initially identified for 47 Navy, Marine Corps, and DLA sites, EDMICS was extended to the Army and Air Force through the DoD's Corporate Information Management initiative in November 1991. In 1993, EDMICS became a joint program (JEDMICS) managed by NAVSUP. Appendix C lists the JEDMICS sites.

JEDMICS installations began in March 1991 and are slated to continue through January 1997 (and more installations are still to be scheduled). JEDMICS will provide the means for DoD organizations to efficiently convert, protect, store, manage, retrieve, and distribute information previously stored on paper or in existing computer systems that have limited capabilities. The goals of JEDMICS are

- to eliminate the use of aperture cards for input, storage, and output purposes;

- to be the repository for data regardless of their original medium;
- to manage multiple data formats;
- to allow users to write data to numerous media; and
- to be accessible through any of DoD's global locators, such as the Naval Engineering Data Acquisition Locator System (NEDALS).

Planning Research Corporation provides the systems integration and technical and management support services to develop and install JEDMICS. This includes an open-systems approach to software development, the integration of commercial, off-the-shelf hardware and software, training, maintenance, site surveys, and system design plans. The JEDMICS contract includes a technology refreshment clause that allows for the incorporation of new technology as it becomes available.

JEDMICS will be used by materiel managers, weapon systems engineers, and depot maintenance personnel. As the standard DoD repository, JEDMICS will provide fully integrated access for other DoD standard systems and applications involved in generating, managing, and using engineering data. JEDMICS operates in an open, client-server environment composed of six distinct subsystems: Input, Data Integrity, Index, Optical Storage, Remote Output (on-site distributed workstations and network printers), and Output. JEDMICS can support both large and small sites using a variety of hardware platforms.

As mentioned in Chapter 1, most engineering in the Army and Navy takes place away from the maintenance depots (the Air Force has located its inventory management, engineering, and manufacturing together). Maintenance depots are not intended as long-term storage sites for JEDMICS data; rather, they are intended to hold data only long enough to support the current active workload and then are expected to delete data. We observed, however, that at least one depot — Anniston Army Depot — not only stored its JEDMICs data, but also modified them. This leads to configuration issues, as two different copies of what are purportedly identical technical data exist in these circumstances. The depots are tending to store JEDMICS data locally today because of communications limitations between the depots and the primary JEDMICS sites. Appendix C contains a brief technical discussion of computer network issues associated with JEDMICS.

JEDMICS' ultimate goal of replacing paper-based and raster-based digital engineering drawings with vector-based digital files is complemented by an activity known as the DoD Automated Document Conversion (ADC) Initiative.[12] This initiative is derived from a congressional directive for DoD to determine if commercially available conversion technologies could economically convert original (nondigital) technical documents to digital formats. The chosen ADC

[12]Created under Public Law 103-335, *Defense Appropriations Act of 1995*, 30 September 1994.

system must be compatible with advanced computer applications for both engineering drawings and textual documents. Recent tests of a candidate system on 200 drawings at the U.S. Army Missile Command produced no usable data and employed formats that were not compliant with either JEDMICS or CALS standards. DoD plans further testing and evaluations.

Digital Product Data Standards

Standards for digital product data address technologies for the storage, retrieval, and exchange of product information. The subjects of the standards range from the lowest common denominator, such as simple pictures, to "intelligent" formats that define all aspects of a product from appearance to tolerances, materials, weight, tensile strength, cost, and delivery information. Each standard has a role to play, but the ultimate goal is to have one universal standard that is a superset of all of the standards described previously in this report. Such an umbrella standard, ISO 10303, *Standard for the Exchange of Product Model Data,* is now under development. Appendix D contains a summary of the components of ISO 10303.

Much development and implementation work needs to be completed before ISO 10303 is truly a universal standard for digital product data. The standard includes a series of application protocols directed toward specific product configurations, characteristics, and applications. To date, only two protocols have been fully approved, while more than two dozen others are in various stages of development, review, and approval.

PRIVATE-SECTOR CASE STUDIES

Boeing Commercial Airplane Group

BACKGROUND

In this subsection, we summarize our findings from an interview with the Spares Department of the Customer Services Division of the Boeing Commercial Airplane Group.[22] Our complete findings are documented in Appendix B. We visited Boeing to collect comparative information on policies, practices, and performance of satisfying customer requirements for spare parts.

Boeing does not maintain commercial aircraft; airlines do. In this respect, Boeing is analogous to DoD's prime contractors and the airlines perform the functions of DoD depots. These airlines, however, rely on Boeing for much more than spare parts, including technical data, initial provisioning, maintenance training, and technical support. Unlike DoD's prime contractors, however, the goals of Boeing's Spares Department are to assume responsibility if an airplane cannot fly and to provide rapid response with a minimal inventory investment by the airline.

Boeing supports almost 7,000 aircraft used by 400 customers (DoD has almost the same number of aircraft in service). The Spares Department manages 4.6 million part numbers and nearly 1 million customer orders per year. The cost of ownership is a major issue with the airlines. Because airplanes are becoming more of a commodity, service and support has increased in significance. Boeing's rule of thumb is that every 10-day increase in spare-part turnaround time increases the airlines' investment in spares inventory by one-third.

SPARE PARTS ORDERS

Spare parts received by Boeing are classified into one of four priorities: Aircraft On Ground (AOG), Critical, Expedite, and Routine. In 1994, Boeing received 879,000 spares orders, of which 504,000 were AOG or Critical.[13] Table 2-9 shows how Boeing satisfies AOG and Critical spare-part orders.

Table 2-9.
How Boeing Satisfies AOG and Critical Spares Orders

Source	Portion of orders (percentages)
Distribution center inventory	70
Boeing manufacturing	15
Suppliers	10
Boeing production inventory	5

Of particular interest to our study is the 15 percent of orders that must be met by Boeing manufacturing. Currently, orders for AOG and Critical Boeing-manufactured parts total 1,500 items per week. These items are made in Boeing's 12 manufacturing facilities. Average lead-times for items that must be manufactured are 7.5 days for AOG items and 9 days for Critical items. In contrast, in 1994 the average lead-time for "normal" production, across all Boeing plants, was 247 days.

BOEING'S EMERGENT MANUFACTURING FACILITY

One Boeing plant satisfying spare-part manufacturing orders is the Emergent Manufacturing Facility (EMF) in Auburn, Washington. It occupies about 440,000 square feet and employs 350 people. The EMF can make almost any metal part, from aluminum to stainless steel, including hard metals. In addition to machining, typical processing steps include presswork, cleaning, testing and inspecting, heat treating, and painting or anodizing.

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[13]Boeing's AOG/Critical customer service operation operates every day, around the clock.

The EMF was built primarily to handle production for spares with priorities of AOG or Critical. Orders with these priorities are worked seven days a week. The facility, however, also does work for new aircraft production and for spares inventory. Spares production represents about 35 percent of total volume. AOG/Critical work, mostly consisting of one-piece lots, represents about 15 percent of total volume. The remaining production orders support new aircraft assembly. A large lot is considered to be one consisting of more than five parts.

This approach to facility sizing represents a dramatic departure from DoD's approach to depot workloading. The depots nominally produce only those parts that cannot be obtained from the private sector. Therefore, depot manufacturing levels fluctuate greatly and capacity is poorly used. Boeing "level loads" the EMF by supplementing "emergency" spares orders with normal production for spares inventory and aircraft assembly. AOG/Critical spare-part orders, when they arrive, assume top priority, even to the extent that production setups will be torn down to make way for them.

Above-the-shop-floor activities — manufacturing engineering, planning, and scheduling — take about 2 days on average, and the flow time from material receiving to final processing averages 4.9 days; total production flow time is therefore 6 to 7 days for AOG/Critical orders. By contrast, the EMF supplies parts of lower priority with an average lead-time of 233 days. About 1,000 orders are open at a given time in the EMF and 300 to 350 jobs per week are completed (by these statistics, the average job is open for 3 weeks).

Commodity Contracting

One Boeing strategy, "commodity contracting," offers a model by which the government might get shorter lead-times and lower costs from its suppliers. The commodity contracting strategy involves identifying potential parts families from Boeing's commodity code database. Each family is then assigned to a single supplier for manufacturing. Table 2-10 shows families developed to date.

Table 2-10.
Boeing Part Families in the Commodity Contracting Strategy

Family	Number of parts
Stamped sheet metal	804
6 in. – 13 in. turned	248
Milled or turned	720
Nonmetal turned	253
Metal milled	4,166
Spars, chords	280
Formed sheet metal	4,100
Major assemblies	2,507

Under commodity contracting, spares performance expectations are now contractual obligations. Reorder lead-times for these parts have been reduced by between 43 percent and 57 percent. The benefit for the supplier is more stable work, which facilitates employment stability and capital-improvement decision-making.

SUMMARY

Boeing's Spares Department focuses on giving superior service with long-term commitments to both customers and suppliers. Its operations offer several lessons for DoD. Boeing has established an internal manufacturing operation expressly to satisfy spare-part orders but runs the operation efficiently by "level-loading" it with lower priority spares and normal production orders. Also, Boeing is getting rapid turnaround on orders placed with its vendors by establishing a commodity contracting program that awards work for a family of parts to a single source.

Kolar Machine, Inc.

Kolar Machine, Inc., in Ithaca, New York, is a machine shop, with 55 employees, that specializes in the production of small batches of precision metal parts for the electronics, computer, and aerospace industries.[23] Kolar provides an example of the lead-times and approaches to automation that are typical of small and medium-sized private-sector machine shops. We give our complete findings in Appendix B.

A typical job at Kolar requires precision machining of a casting and its subsequent coating or painting. Production quantities of 10 to 50 units are common, but production of single prototypes and batches of 2,000 have been undertaken. Kolar's quoted response times are usually six to eight weeks. Kolar's responsiveness is largely dependent on casting availability, which averages four to six weeks. One customer in the electronics industry has signed a long-term purchase agreement with Kolar with the requirement that orders placed on Monday be filled the following Monday.

Kolar operates with a fully staffed first shift, and a skeleton manufacturing crew of machine operators and a supervisor on the evening shift, to handle peaks in demand. When demand is sufficient, a horizontal machining center can be run unattended through the third shift.

Kolar's precision shop is composed of numerically controlled equipment, including 18 vertical and horizontal machining centers and 2 turning centers, and manual equipment. All numerically controlled machines have automated tool changers, and many of the horizontal machining centers have two pallets for advance setup. The operation of this equipment requires skilled workers. Kolar has recognized the cost of recruiting and training such a work force and attempts to retain them with good management practices and generous (for the local economy) pay and benefits package.

An estimated one-third of Kolar's revenues is generated from manual equipment. For example, Kolar maintains a bank of 12 drill presses that remains set up with the most commonly used drills and taps for rapidly completing these operations in support of operations completed on its numerically controlled machines. While some of Kolar's manual processes could be automated, economics drive the decision on whether to do so. Manual processes are retained when automation will likely increase the capital invested, with insufficient reduction in lead-time or operating expenses, or improvement in quality.

Kolar's interface with the customer is slowly moving toward an electronic medium, but currently the engineers work from blueprints that contain part specifications. Responding to a request for quotation (RFQ), Kolar will generate a complete numerical control program that accurately measures the machine time required to produce the part. Kolar's pricing is based solely on machine hours.

Small shops, such as Kolar, that work with local banks do not generally have the resources to make investments in facilities, equipment, or people unless they get near-term returns on these investments or special circumstances arise. To position itself to take advantage of a changing market, Kolar has chosen controlled, revenue-financed growth rather than growth achieved through heavy debt or acquisition, which may leave it financially weakened and unable to survive the next recession.

Current plans call for preparations to add numerically controlled machines at a rate of one or two per year (a $500,000 to $750,000 investment) as business opportunities develop. Although Kolar has thus far chosen not to acquire competitors (or operations that customers have targeted for closure), it has purchased equipment at bankruptcy sales. Even with the market's growth potential, the firm still finds the market to be intensely competitive and is forced to closely monitor its investments and expenses.

SUMMARY OF INITIATIVES

Three programs and one Joint Center comprise the DoD's formal FCIM initiatives. In addition, any inventory-management, engineering, or manufacturing site that has made process improvements, lead-time reductions, or technology acquisition has tended to label the effort as "FCIM." While these site-specific efforts are real, they have been conducted at the site level and not at the military services or DoD level.

The Navy RAMP Program has, through government sponsorship, developed a suite of hardware and software products for managing engineering and manufacturing better. RAMP products have been implemented at a number of Navy and Army sites, with essentially no Air Force participation. RAMP products are marketed by SCRA and are available on the commercial market. The Army's FCIM Program has developed the concept of "modules" for supplying a category of parts. These modules are conceptual organizations that cut across DoD boundaries and consist of inventory management, engineering, and depot manufacturing sites. Using this concept, the Army has provided funds to its depots so that they can acquire technologies that reduce engineering and manufacturing lead times.

The Air Force's SPARES Program takes a more focused view than similar Navy or Army programs. The goal of the SPARES Program is to streamline the procurement of parts by concentrating on the largest component of lead-time — creating, storing, and accessing technical data that are not currently in digital format. The Joint Center for FCIM acted as an advocate for lead-time reduction across the military services. It has facilitated and funded a number of relatively small-scale efforts for reducing spare-part procurement lead-time across the services.

Several initiatives related to FCIM have an effect on spare-part procurement lead-time and on future engineering and manufacturing technologies. The JEDMICS Program will provide a standard electronic library for DoD technical data in a variety of digital formats. The emerging ISO 10303, *Standard for the Exchange of Product Model Data,* offers to make the interface between different proprietary CAD and manufacturing planning systems much smoother.

Private-sector practices offer some relevant lessons. At Boeing, an emergency spare-part manufacturing facility is level-loaded with nonurgent spares and assembly-part orders. This tactic keeps response times high and overall costs low. At Kolar Machine, Inc., a small machine shop, investments are made selectively, targeting only the highest immediate payback, and are kept within the financial reach of the company.

CHAPTER 3

Analysis

In this chapter, we discuss the further implementation of FCIM technologies. Issues to be considered include: the future structure of the depot system; the prospects for moving manufacturing workcells among depots or to private management; the need for conducting a complete business case before implementing FCIM further; and the related area of technical data.

STRUCTURE OF THE DEPOT SYSTEM

Before contemplating strategies for further implementing FCIM technologies and techniques, we recommend that DoD establish the future structure of its depot manufacturing base. While a substantial amount of analysis has been done in conjunction with the Base Realignment and Closure Commission, that work has focused on products and little has been done from the perspective of manufacturing processes. Major questions that must be answered before DoD can implement FCIM further include the following:

- How many depots (and associated manufacturing sites) will there be, and where will they be located?
- How will manufacturing capabilities be distributed among the depots?
- For each manufacturing capability, how much defense manufacturing capacity will there be — enough to satisfy peacetime workload plus a reserve for wartime?
- Which parts should be routed to defense depots for manufacture?

These questions are interdependent. For example, the amount of capacity to carry depends on the parts that will be made in the depots. As long as these questions remain unanswered, however, reliable cost/benefit projections for manufacturing investment proposals cannot be made.

Workload

The manufacturing workload at defense depots has a peacetime component, which is the normal business mode, consisting of support to depot repair (which entails having manufacturing capability but not making parts from scratch) and satisfying peacetime supply-system orders for replacement parts. Over and above this peacetime component is a wartime surge capability. Our study focuses on peacetime manufacture of replacement parts. We found that the policy defining that workload is clear: the depots should manufacture parts for which no private-sector source exists or for which the private-sector source cannot respond effectively to cost, schedule, or technical requirements. We also found no evidence that the depots were violating this policy. We recommend that DoD study the issue of contractor reluctance to bid on parts and identify its root causes. One possible cause is incomplete or incompatible technical data, discussed later in this chapter.

Estimating depot workload is a key element in determining how much depot manufacturing capacity should be carried. We observed that depot manufacturing workload is poorly defined beyond aggregate measures, such as overall direct labor hours. The identification of parts meeting depot manufacturing criteria is largely reactive — after a demand occurs — and little work has been done to identify specific parts, anticipate their demand and workload, and adjust the capacity of the depots that will eventually make them. While predicting replacement-part workload can be difficult because of the uncertain nature of failures, estimating required capacity (beyond simply guessing) in the absence of such predictions is virtually impossible.

The nature of depot workload is changing. The decline in defense operating tempos and the consolidation of some depots has led previous workload expectations to become inaccurate. While programs such as RAMP and FCIM have targeted specific levels of work (e.g., 15,000 parts per year, in batches of 5), those workloads are not tied to specific part numbers and have not materialized at the facilities implementing the programs' technologies. We recommend that depots implementing major manufacturing technology systems analyze their potential workload on the basis of part numbers by getting estimates from inventory managers on the nature and extent of manufacturing work destined for the depot.

Capacity and Utilization

DoD uses a definition of capacity that is significantly different from that used in the private sector. The Department defines capacity as "the amount of workload, expressed in actual direct labor hours, that a facility can effectively produce annually in a single-shift, 40-hour week, while producing the product mix that the facility is designed to accommodate."[24] The Department of Commerce, in its *Survey of Plant Capacity*, does not specifically state the shift configuration that should be used for calculating capacity. Rather, it defines the concept of "full production rate," which is "the maximum level of production an establishment could attain under normal operating conditions."[25] Commerce also defines the "national emergency production rate," which is "the maximum level of production an establishment can expect to sustain for one year or more under national emergency conditions."[25]

The full production rate is considerably greater than the one-shift capacity definition used by DoD. In 1992, the latest year for which full data are available, the civilian manufacturing sector utilized 76 percent of the full production rate (i.e., capacity) and used 60 percent of the national emergency production rate. While Commerce does not report the typical shift configuration corresponding to full production, this configuration can be estimated. Assuming that national emergency production is equivalent to running two shifts, 10 hours per day, for six days per week, then the overall civilian *actual* production rate would be equivalent to about 1.8 8-hour shifts working 5 days per week. This is almost twice what DoD defines as its capacity. Similarly, the overall civilian *full* production rate would be equivalent to about 2.4 shifts working 5 days per week. This latter figure quantifies the civilian definition of capacity.

To compare defense depots' capacity utilization with that of the private sector, we must use an equivalent definition of capacity. In Table 3-1, we show DoD estimates of capacity utilization for a sample of depots, as well as LMI estimates of capacity utilization that result from applying the Commerce definition and our assumption of the national emergency shift configuration. The LMI estimate is derived by dividing the DoD estimate by the equivalent civilian full-production rate of 2.4 shifts. Recognizing that our assumption about national emergency production could be wrong, we also tabulated a "worst-case" scenario (which is the "best case" from the depot's perspective) in which national emergency production achieves only a 2-shift, 5 days per week level. In this case, the civilian full production rate divisor would be 1.6 shifts rather than 2.4 shifts.

Table 3-1.
DoD and Civilian-Equivalent Capacity Utilizations

Depot	DoD estimate[a] (percentage)	Civilian industry equivalent[b] (percentage)	"Best-case" civilian industry equivalent[c] (percentage)
Anniston Army Depot	91	38	57
Tobyhanna Army Depot	69	29	43
Naval Aviation Depot, Cherry Point	98	41	61
Ogden Air Logistics Center	62	26	39

Sources: Department of Defense, *Business Plan Fiscal Years 1995–1999*, Defense Depot Maintenance Council, 11 January 1995; Department of Commerce, *Survey of Plant Capacity, Final Report for Fourth Quarters 1989–1992*, MQ-C1(92)-1, March 1994.

[a]Based on a one-shift, 40-hour per week operation.

[b]DoD estimate divided by 2.4. Based on the Department of Commerce's definitions of "full production capacity," "national emergency production," and assuming that national emergency production constitutes two 10-hour shifts working 6 days per week.

[c]DoD estimate divided by 1.6. Based on the Department of Commerce's definitions of "full production capacity," "national emergency production," and assuming that national emergency production constitutes two 8-hour shifts working 5 days per week.

The FCIM initiatives we examined focus on two manufacturing processes: SMPs machining and PWA fabrication. For these processes, DoD appears to have substantial excess depot machine capacity; in our visits to depot manufacturing shops, we observed machine use ranging between 10 percent and 50 percent of capacity. These observations are consistent with the depots' overall utilization rates, when defined as in the commercial sector. In addition to excess capacity, manufacturing capabilities are duplicated across depots. Of the facilities we visited, both Tobyhanna and Indianapolis, for example, can fabricate PWAs. Anniston, Cherry Point, and Watervliet can produce SMPs.

With the failure of expected workloads to materialize, the underutilization of available capacity, and the duplication of capabilities, DoD may need to consolidate depot manufacturing capabilities further. We note, however, that while some or most of any given manufacturing capability (e.g., metalworking) may be further consolidated, a certain amount must remain at the depot to preserve support for repair operations. We also caution that duplication of general capabilities does not imply duplication of more specific capabilities. Each facility possesses some equipment and expertise that is unique within the DoD depot system; such unique capabilities should be factored into any assessment of consolidation. While a determination of appropriate depot manufacturing capacity is beyond the scope of this study, we stress that our following recommendations to increase utilization should be applied only after depot manufacturing capacity is adjusted by privatization or consolidation.

We believe that the defense practice of defining capacity on the basis of a single shift and leaving wartime capacity unused degrades readiness for wartime production and diminishes economic utilization of plants and equipment. Machinery must be used to be ready for contingencies. The Defense Depot Maintenance Council agrees, saying, "In order to be effective, Core capability must be constantly exercised."[26] When machines sit idle, they deteriorate. Sometimes calibration is lost.

Excessive idle capacity wastes money. At Watervliet Arsenal, for example, wartime reserve capacity is normally included in the burden rates of peacetime production. We found burden rates roughly three times those of comparable commercial operations. While some of the differences can be explained by the unique nature of Watervliet's mission, we believe the large amount of idle equipment at that facility is a substantial factor. In another example involving Watervliet, covering a machine with a tarpaulin for an entire fiscal year changes its accounting status and removes it from the burden rate. Of course, the true cost of the machine is independent of whether or not it is covered by a tarpaulin. This practice also leads to irrational production strategies, such as running large lots of parts one year to avoid having to run the machine in another year and thereby incur a year's worth of burden.

We looked to a commercial firm, Boeing, for capacity and utilization strategies that might apply to defense depots' manufacturing mission: providing long-term support for parts with low quantities and uncertain timing. At Boeing's Emergent Manufacturing Facility, about 35 percent of capacity is devoted to production of spares. This work is supplemented by "normal" production orders for Boeing's aircraft assembly plants. Spares orders have priority, keeping responsiveness high. The supplemental production keeps utilization high and smoothes the production schedule.

Commercial practices, such as those at Boeing, provide a useful model for that capacity which DoD chooses to retain in-house to fill requirements when contractors cannot or will not meet its needs. To use that capacity economically, we recommend that DoD change its policy and permit the peacetime use of depot machinery that exists for wartime production. Using the Department of Commerce definition, capacity utilization at defense depots is less than 50 percent, in some cases much less. Private-sector capacity utilization averages between 75 percent and 80 percent; that should be a goal for the depot capacity that exists after privatization or consolidation.[25] Such peacetime work should be of such a nature that it can be readily preempted should a crisis develop. To avoid government production that could otherwise be awarded to private contractors, the depots should be encouraged to find alternate uses for their unused capacity, such as leasing machine time to local manufacturers. This would require new DoD policy. While U.S. law permits DoD to lease real and personal property (and explicitly allows private contractors to lease government test facilities), there is no DoD policy outlining the leasing of depot manufacturing capability to the private sector.[27, 28]

Moving Manufacturing Workcells

We were asked to examine whether depot manufacturing workcells could be relocated to other depots or to private-sector companies. We found that DoD's FCIM initiatives have not generally created stand-alone manufacturing workcells. While some depot manufacturing shops are physically separate from the broader depot operations, in almost every case those shops' information systems — such as for order entry, job scheduling, personnel, and accounting — are intimately entwined with the depot's business systems. Because of the links between these shops and their host depots, we conclude that it would be impractical to consider moving the operations, as configured, to other locations. While DoD could certainly reallocate or sell its capacity (e.g., individual machine tools), moving an entire operation would involve significant reconfiguration and reinstallation of the associated control systems.

It would be technically feasible for a private-sector firm to assume management of a government-owned manufacturing shop, if the entire depot that contained the shop were government-owned, contractor-operated (GOCO). We question the economic feasibility, however, because of the excess capacity currently carried in those shops. It also would be technically feasible for a private firm to operate a depot's manufacturing shop (on a concession basis), but under today's policies, major issues of sharing material-handling (into and out of the shop), utilities, equipment, and other support-services costs would need to be resolved first. Because of the degree of systems integration between manufacturing shops and their parent depots, substantial management and accounting issues would have to be resolved if the shop alone — but not the entire depot — were to become GOCO.

One of the justifications for DoD's funding development of RAMP hardware and software was its potential desirability to private industry. The government has limited rights and therefore limited ability to transfer RAMP products to the private sector. SCRA, however, has the ability to sell RAMP products directly to the private sector or to license them for distribution. Private-sector shops will view RAMP products as any others that are available to them through the marketplace and will choose those that best suit the technology and economic needs of their business.

Whether RAMP will be successful in the marketplace is still unclear. Investment in the full suite of RAMP technology would increase the capitalization of the typical small machine shop (15 to 20 machine tools) by 100 percent or more. Such an investment would require a sizable and rapidly growing operation to justify its fixed and semifixed costs. Private shops are more likely to apply RAMP products incrementally, as they do with other technologies, as funding and payback warrant.

DoD can improve the responsiveness of its contractors by changing the way it buys spare parts. Boeing, for example, has created eight parts families for spare parts that it purchases. Each family consists of from 200 to several thousand parts that share design and manufacturing features, and Boeing awards its entire requirement for parts in a given family to one or two suppliers. This concept is currently being explored by DLA in its On Demand Manufacturing program.

Further FCIM Implementation

The technology behind DoD's depot manufacturing initiatives is sound. Although some modules of RAMP are still under development, the hardware and software perform as advertised. The same applies to technologies implemented by the Army FCIM Program and the Air Force SPARES Program. For the part orders that have been processed using these technologies, lead times and marginal costs are substantially lower than they previously would have been. From a business standpoint, however, those orders have been insufficient to demonstrate that the FCIM technologies have produced net benefits. Those benefits must be shown to outweigh the costs of developing, implementing, and supporting the technology. We found few data upon which to evaluate the return on investment of DoD's FCIM initiatives or upon which to prioritize future implementations. We conclude that, although the technical programs are robust, the business case supporting implementation at specific depots has not been well defined.

Initiatives for improving depot manufacturing that require substantial investment should be accompanied by a business case defining the investment and expected return. Key elements of that business case should include

- the universe of parts affected;
- characteristics of parts in the universe of parts — their materials, designs, and processes;
- characteristics of demand for those parts — demand history, users, demand forecasts, demand variability, and required lead-time;
- characteristics of current responsiveness to demand — cost, quality, lead-time profiles, and inventory (for stocked items);
- aspects of the manufacturing operation to be affected (status quo);
- technical proposal (future operating scenario);
- full accounting of expected costs, benefits, and timing;
- economic analysis of cash flows;
- major risks, including actions required for project success but outside the depot chain of command (e.g., the project depends on an item manager sending orders to the depot); and
- metrics for gauging implementation progress.

The government has a substantial investment in RAMP, having funded much of the development work. While there might appear to be certain benefits to implementing standard RAMP engineering and production systems in all facilities, we found that the RAMP installations differ from facility to facility. Different depots use different modules, in different versions, with different links into the host depot's other systems. The government is attempting to make RAMP Program hardware and software even more modular, which is a healthy development because of the diversity of depot missions and systems. RAMP-like products are also available from other commercial vendors. RAMP does appear to have an edge in process planning tools and is poised to use emerging standards under ISO 10303. We conclude that, given an adequate business case, the depots that will use the technology are in the best position to determine the vendor. The government's interest in RAMP development represents a sunk cost and should not be a factor in further installations; RAMP products should stand on their own merit in the marketplace.

TECHNICAL DATA

Technical product and process data in electronic format is the glue that binds the components of computer-integrated manufacturing together. DoD's policy is to acquire technical product data with initial procurements of all new systems except where those data are proprietary or when a conscious decision is made to acquire life-cycle logistics support from the contractor. In practice, however, DoD sometimes finds itself with no (or incomplete) technical data and no contractor support. This can occur because

- the policy is not enforced, often because the cost of acquiring a full technical data package is considered too high;
- the life-cycle support contractor fails or becomes extremely expensive; or
- unanticipated replacement of parts is required, such as when a part's service life extends well beyond what was planned during the initial design, procurement, and provisioning.

When this occurs, DoD must develop technical data for replacement parts through reverse engineering. Sometimes parts must be redesigned because the materials or underlying design technology have changed. Reverse engineering and redesign must take place regardless of whether the part is then manufactured in a depot or by the private sector.

Despite DoD's policy of acquiring access to technical data, there will always be circumstances in which the complete technical data simply do not exist. DoD must have a mechanism in place to respond to these aberrations. The creation or updating of technical data is currently done primarily by the government but could be contracted to private-sector design firms. The same process of analyzing workload and capacity that we applied to production earlier in this chapter could be applied to engineering activities that create technical data. One key difference that we observed, however, is that, whereas depot equipment capacity far outstrips current production demand, the government engineering sections we visited were busy.

Although the current cost of maintaining technical data is high, it is likely to come down as new standards evolve. DoD supports a number of programs related to the creation, use, and communication of digital technical data. The Joint Engineering Data Management and Information Control System, the Automated Document Conversion Initiative, ISO 10303, and similar efforts will all provide standards and technology that is potentially useful to both depots and private-sector suppliers.

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APPENDIX A

Maintenance Depot Case Studies

ANNISTON ARMY DEPOT

Anniston Army Depot is responsible for the maintenance and overhaul of heavy combat vehicles and small arms.[1] The depot, with 96 maintenance buildings and 1.5 million square feet of shop space, occupies more than 15 thousand acres and is valued at $176 million — $38 million for maintenance facilities and $138 million for industrial equipment. The depot's work force exceeds 3,300 civilian employees and has an annual operating budget of $280 million and an annual payroll of approximately $150 million. Of the 3,300 employees, 2,000 are in depot maintenance, with 1,565 are direct labor personnel. Seventy-three percent of the workload is related to combat vehicles. Major programs include the following:

- M1 Abrams Tank
- AGT 1500 Turbine Engine
- M60 Series Tank
- M881 Recovery Vehicle
- M728 Combat Engineering Vehicle
- M551 Armored Reconnaissance/Airborne Assault Vehicle
- Armored Vehicle-Launched Bridge
- .50 Caliber Machine Gun
- Recoilless Rifle.

Anniston possesses extensive industrial capabilities:

- Personnel — fabrication planners, computer-aided design (CAD) technicians, computer numerically controlled (CNC) programmers, machinists, tool die makers, certified welders, chemists, and engineers (manufacturing, industrial, mechanical, material, chemical, and electronic)
- Quality control — metrology laboratory, chemical laboratory, metallurgical laboratory

- Welding — ballistic armor, metal and tungsten inert gas, CNC dabber, CNC electron beam, robotic, and resistance
- Conventional and vacuum brazing
- Conventional and robotic metalizing
- Conventional and CNC grinding
- Cleaning and finishing processes — chemical cleaning, abrasive blasting, plating, painting
- Fabrication — heat treating, sheet metal, and CNC flame plasma cutting
- CNC machining — milling, turning, electrical discharge, and Gantry Machining Center (60'x20'x10' with 100 hp spindle to handle work up to 30 tons)
- Upholstery — for example, canvas, leather, nylon, rubberized fabrics, gaskets, metal data plates.

Of these capabilities, we focused on the machining of metal parts. Anniston is the site of a Rapid Acquisition of Manufactured Parts (RAMP) small mechanical parts "cell." The cell is not isolated, but rather has been integrated into a previously existing machine shop. RAMP installation began in 1992. The shop consists of CNC and conventional machine tools and RAMP shop-floor control computers and software. The Army bought the machine tools over time since the 1970s, using its asset capitalization program. The shop's engineering office has RAMP hardware and software (e.g., for manufacturing engineering and production control) as well as third-party systems for drafting, engineering analysis, and CNC programming. As with the machine tools, the latter were acquired before RAMP, using approximately $1 million of Defense Business Operating Funds. The RAMP products were procured for approximately $9 million, using funds from the Army Flexible Computer Integrated Manufacturing (FCIM) Program. That figure includes initial hardware, software, and associated shop-floor equipment, such as tool presetters and modular fixtures. Ongoing license and maintenance fees for the RAMP software cost about $200,000 per year and are being funded by the RAMP Program Office.

About five new orders per day are started in this shop. For the period between December 1994 and January 1995, the number of parts per order ranged from 2 to 575, with the average being 73. During that period, the average order spent 17 days in process planning and 13 days on the shop floor. A review of the Order Status Report in February 1995 showed 140 open orders.

As noted above, the shop contains both CNC and conventional equipment. Not all parts are made start to finish in this shop. Parts requiring welding, plating, sheet-metal work, and other nonmachining operations have that work done in other buildings. Also, some machine-shop orders are so small or otherwise of such a nature that they essentially bypass the engineering office and are released to the conventional equipment section. There, skilled operators select tooling, build what fixtures they need, and make the parts with minimal engineering instruction. About 1 order in 10 is routed to the conventional equipment section.

According to shop management, the only parts made in this shop are those with long private-sector lead-times, parts that have a requirement inside the private-contractor delivery schedule, or parts for which the private sector is not responsive or prohibitively expensive. While drawings and other technical data are usually partially available, they usually must be supplemented by redesign or reengineering. For example, the original specification may call for a part to be made from a casting; in small lots, fabrication from a billet may be more economical. In another example, the original metal may no longer be a stock mill product, and the Anniston engineers must find a suitable alternative. We observed both of these cases during our visit.

In 1990 the South Carolina Research Authority (SCRA) — developers of RAMP — prepared a site survey of the Anniston depot machine shop. In the summary of that survey, which was made available to us, SCRA characterized the performance of the shop in terms of number of work orders, size of the orders, and lead-times in the shop. We do not know if the analysis extended to the universe of candidate parts or to an economic assessment of the costs and benefits of the RAMP installation.

The shop is small, employing about 35 machinists, 9 engineers, and some support staff. The number of machines, however, far exceeds the number of operators and capacity utilization appears low. The Defense Depot Maintenance Council estimates that overall Anniston's FY95 capacity utilization is 91 percent, but that estimate is based on a one-shift operation working 40 hours per week.[2] Anniston's management would like to sell machine time to local manufacturers on second and third shifts, but Army regulations do not permit it. Under a new arrangement, Anniston is working as subcontractor to United Defense.

We asked manufacturing managers at Anniston to comment on the perception that they have been manufacturing relatively large batches of parts in possible contradiction to DoD policy. In response, Anniston researched 653 orders placed on its machine shop. Only eight were for quantities exceeding 500; the part types included welding pads, bushings, and leg extensions. One item worked on in large quantities was National Stock Number 1015-01-305-4469, *Modification Kit, Gun, Weapon* (also known as a muzzle reference sensor columator). This item was manufactured by a private contractor for the supply system but was delivered defective and unserviceable. Anniston modified 3,000 of these columators by drilling four holes and installing larger screws into the holes and returned the items to stock. Short of conducting a complete, independent audit of Anniston's work orders, we find no evidence of large-volume manufacturing that would be contrary to DoD policy.

NAVAL AIR WARFARE CENTER, AIRCRAFT DIVISION, INDIANAPOLIS

The Naval Air Warfare Center (NAWC), Aircraft Division, in Indianapolis, Indiana, has installed a printed wiring assembly (PWA) shop that uses RAMP hardware and software.[3] The 30,000-square-foot facility contains a clean room for production and assembly. The facility was completely developed from the ground up and is not integrated into other manufacturing and repair systems at Indianapolis. Although electronic data interchange is used for procurement, the facility uses the NAWC procurement system and has not installed the Automated RAMP Logistic Support System (ARLSS).[1] Total development cost to date has been $24.6 million, as detailed in Table A-1.

Table A-1.
Printed Wiring Assembly Shop Expenditures (millions of dollars)

Category	Expenditures to date
Building	7.5
Equipment (pre-FY95)	13.2
Equipment (FY95)	0.6
Support	3.3

The facility supports both manufacturing and assembly of PWA components and maintains a multiple-level bill of materials to track manufacturing and assembly. Included in the equipment costs is an automated storage and retrieval system for handling materials, work in process, and finished goods. The operation of this system incurred a large lead-time penalty, and its operation has been discontinued. In its place the RAMP cell has adopted a continuous-flow production strategy, in which boards move directly from one work station to the next without entering the storage and retrieval system.

Industry-standard data sets can be generated from electronic and paper formats, but, typically, reverse engineering techniques must be used to develop digital product data. Intergraph software is used to develop the digital data package, and Computervision software with Symbolic Inference Engine is used for process planning, manufacturing, and routing. Indianapolis personnel estimate the process of developing the digital technical data from reverse engineering and conversion of paper data for manufacturing release consumes $15,000 per part number.

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[1]ARLSS comprises a manufacturing administrative database system, an electronic bid system, and a cost and performance measurement system.

The NAWC's RAMP site responds to work orders from local material managers, the Defense Logistics Agency (DLA), the Navy's Aircraft Supply Office, and the Navy's Ship's Parts Control Center. As of 8 March 1995, the facility had produced 48 different PWAs. A total of more than 1,000 boards have been produced, with an average production batch size of 12.

On the shop floor, the Indianapolis RAMP operation has produced PWAs 24 percent faster and 27 percent cheaper (on a marginal, not total, cost basis) than the typical traditional supplier. Rework is down 87 percent, and what remains is caused by production errors and not errors in the reverse engineering process.

Overall, however, a return on the investment in Indianapolis' RAMP facility appears distant. In the past year, NAWC produced 23,500 boards of 1,450 types in non-RAMP facilities. The product and process data for those boards was not, for the most part, in electronic format. If those boards had been made in the RAMP cell, Indianapolis would have incurred an additional $22 million (1,450 boards at $15,000 per board) to develop the digital technical data required for RAMP processing (plus, we believe, additional capital investment in engineering workstations to handle the volume). Indianapolis personnel estimate that production of those same parts in the RAMP cell would save $132,000 per year. Those savings would not nearly offset the required investment of more than $46 million — $24.6 million for the facility and $22 million for engineering.[2]

The RAMP facility is operating at less than 10 percent of its manufacturing capacity (it was idle during our visit). There are a number of reasons for this low utilization:

- Manufacturing resources in all the services operate at low utilization rates in peacetime.
- An imbalance likely exists between the resources needed to generate the digital data and the manufacturing resources they feed (i.e., the engineering support is a bottleneck) such that the production facilities will often be starved.
- Item managers, who have at their discretion the authority to direct work to the RAMP workcell, may not be aware of the workcell's capability or may be selecting other sources because the workcell has little history upon which managers can assess its reliability.
- In the past, DLA has attempted to avoid stock outages of long-lead-time items by maintaining high inventory levels. As a result many of the parts that could be sourced at NAWC's PWA RAMP facility have no current requirements and may not for some time in the future.

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[2]The present value of $132,000 per year for infinity at a 10 percent discount rate is $1,320,000.

- RAMP PWA facilities were designed to support the engineering and manufacture of circuit boards with through-hole mounting of components. Through-hole technology is becoming a smaller portion of the PWA part-number universe as surface-mount technology is gaining wider acceptance. As the technical information required to support surface mount boards is the same as through-hole, NAWC's RAMP site will start to absorb these activities.

NAVAL AVIATION DEPOT — CHERRY POINT

The Naval Aviation Depot in Cherry Point, North Carolina, services fixed- and rotary-wing aircraft for the Navy and Marine Corps.[4] The depot employs 3,000 people, 1,800 of whom work in maintenance. Eight major aircraft programs are presently underway.

Cherry Point uses RAMP products in two shops: a mechanical-parts metal-working shop and a turbine-engine blade- and vane-repair shop. The depot has been a RAMP R&D site since 1988. The metalworking shop uses RAMP products for

- communications support and network control,
- order management,
- shop-floor control,
- tool image storage, and
- bid preparation.

The RAMP modules for macro and micro process planning do not meet Cherry Point's needs at the present time, particularly in the area of multiple-axis machining. The shop gets about 5 orders per week and has about 120 open orders in the system.

The blade and vane repair shop works only on items that otherwise would be scrapped. Thirty percent of the items entering the shop can be returned to service. Workload varies from 20 to 100 orders per week. The blade and vane facility uses the RAMP products for

- communications support and network control,
- order management, and
- shop-floor control.

The blade and vane operation does not need the RAMP manufacturing-engineering or process-planning products. Because all work is repair, the engineering department creates, for each part number, a list of processes that might apply to that part's repair. When an order arrives, an engineer on the shop floor inspects the parts and tailors the process list to what the individual parts need (crossing off, modifying, or adding process steps). The blade and vane facility's RAMP products were purchased with depot productivity improvement funds, with the RAMP Program Office supplying funds for R&D-related activities. The facility is operating at about 20 percent capacity utilization because the number of air wings and flight hours has declined since its design.

The Defense Depot Maintenance Council estimates that Cherry Point's FY95 capacity utilization is 98 percent.[2] That estimate is based on a one-shift operation working 40 hours per week. Management at Cherry Point would like to expand facility utilization. No mechanism exists, however, to routinely handle orders originating outside the depot or the Navy's Aviation Supply Office (site of Cherry Point's inventory management function). Although Cherry Point is working with McDonnell Douglas on the AV-8B aircraft and as a subcontractor to Bell/Boeing for V-22 aircraft ground support equipment, Cherry Point management points to a lack of DoD policy for using their capacity for other government or private work. In the past they were allowed to compete with other depots for work, but that policy has been discontinued.

OGDEN AIR LOGISTICS CENTER

Ogden Air Logistics Center (OO-ALC) is located at Hill Air Force Base, Ogden, Utah. OO-ALC is responsible for the maintenance and overhaul of strategic missiles, aircraft systems, flight simulators, trainers, aircraft components, and photographic and reconnaissance equipment. The base occupies more than 960 thousand acres, with 239 industrial buildings and 4.0 million square feet of shop space. The total facility value is $1.5 billion, with a plant equipment value of $471.8 million. The logistic center's work force totals 10,299 employees and an annual payroll of approximately $385 million. Major programs at OO-ALC include

- the MINUTEMAN strategic missile;
- the Peacekeeper strategic missile;
- F-16 aircraft;
- RF-4C aircraft;
- C-130 aircraft;
- OV-10 aircraft;
- radar fire control and navigation systems;

- photographic and reconnaissance equipment;
- flight simulators and trainers; and
- landing gear, wheels, brakes, and struts.

In support of its depot maintenance activities, OO-ALC possesses substantial engineering and manufacturing capability. The following are some of the skills and processes available to support manufacturing:

- *Personnel* — design engineers, CAD technicians, CNC and numerical control (NC) programmers, machinists, solderers, and electronic technicians
- *Fabrication* — drilling, turning, forming, milling, sheet-metal working, multiple-layer printed circuit boards (analog and digital) fabrication, advanced composite manufacturing, and plastic injection molding
- *Test and inspection* — resonant ultrasound inspection system, neural radiant energy detection system, nuclear hardness test facility, fiber optics, and advanced compact radar test ranges
- *Cleaning and finishing* — glass and plastic media blast, ultrasonic cleaning, plating, and painting.

OO-ALC has a robust manufacturing facility that is grossly underused. The Defense Depot Maintenance Council estimates that OO-ALC's FY95 overall capacity utilization is 62 percent.[2] That estimate is based on a one-shift operation working 40 hours per week. At the time of our visit, capacity utilization was between approximately 10 percent and 15 percent. Indications were that utilization had been much higher in the past. The facility is equipped with both modern and vintage CAD and computer-aided manufacturing (CAM) equipment. Engineering and manufacturing functions are collocated.

The Air Force's Spare Parts Production and Reprocurement Support (SPARES) Program, an FCIM initiative, has sponsored projects in the areas of technical data management and feature-based manufacturing. With SPARES, engineers use an optical storage and retrieval system to streamline the scanning of technical data into digital form and subsequent use of those data. A software program called Feature-Based Manufacturing Center (FBMC) helps engineers create NC programs for the machining of bushings. FBMC is a microcomputer-based application that is designed to overcome programming difficulties associated with older, proprietary-language machines. Using FBMC to create programs for Mazak, Cincinnati Milicron, and Warner Swasey machines has cut programming time from 3 to 4 hours to 10 to 15 minutes. The FBMC system cost approximately $350,000, which OO-ALC found to be a cost-effective alternative to a larger and more complex RAMP installation. Although most of the workload performed within the engineering facility is in support of depot maintenance, OO-ALC also produces technical data packages for both in-house and commercial manufacturing.

TOBYHANNA ARMY DEPOT

The Tobyhanna Army Depot in Tobyhanna, Pennsylvania, performs maintenance — including upgrade and replacement parts manufacture — of communications and electronic equipment.[5] Major programs currently worked at Tobyhanna include

- the VRC 12 family of radios,
- the Single Channel Ground and Air Radio System (SINCGARS),
- satellite communications,
- teletypes,
- communications shelters, and
- radar equipment.

Tobyhanna's total installation occupies 1,293 acres and employs 3,500 civilians. Eleven maintenance buildings with an estimated replacement value of $14.1 million house $132.5 million of industrial machinery and equipment.

Tobyhanna is undergoing a major upgrade in its PWA manufacturing capability. The goal is to not only upgrade shop floor equipment but also to streamline and integrate the flow of all information between the request for quotation and the delivery of the product. State-of-the-art process equipment (e.g., chip placement and board soldering machines) is being installed in a newly renovated shop. In the engineering offices, Tobyhanna has installed RAMP hardware and software for PWA process planning. The RAMP products are an integral part of the upgrade (i.e., they do not form a stand-alone manufacturing cell.). Other software products, for example, help perform finite element analysis and circuit card simulation to verify designs before their manufacture. Funding for the upgrade has come from the Army FCIM Program, the RAMP Program, and the depot's industrial fund.

The decision to use Tobyhanna normally is made by the Communications and Electronics Command (CECOM) or a program manager and is based on availability (or lack thereof) of a supply source and technical data and drawings. Most of Tobyhanna's work is because industry has turned the work down, the commercial source has dried up, or the system is obsolete and has no support base in the private sector.

Tobyhanna devotes about 200 staff-years per year to circuit-card engineering and manufacturing. The depot produces approximately 1,000 to 1,500 boards per month, with a typical lot size of 10 boards. Some production runs may run up to 200 boards. Where technical data (drawings or process plans) are incomplete, they are completed by Tobyhanna engineers.

The Defense Depot Maintenance Council estimates that Tobyhanna's FY95 overall capacity utilization is 69 percent.[2] That estimate is based on a one-shift operation working 40 hours per week. It is difficult for Tobyhanna to determine workloads and schedules, because Tobyhanna does not receive reliable award schedules from the inventory managers. Also, some requests for quotes represent independent government estimates of private-sector work and are not destined for a depot. Tobyhanna does not know which requests represent real solicitations for depot work and which represent independent government estimates.[6]

WATERVLIET ARSENAL

Installation Overview

The Watervliet Arsenal (WVA) is located on the west bank of the Hudson River, seven miles north of Albany, New York. WVA is the oldest continuously active arsenal in the United States. The arsenal's work force numbers about 2,100.

The primary mission of the arsenal is manufacturing[3] but the location of Benet Labs at the same site allows for comprehensive management of a weapon system's life from concept generation through research and engineering, prototype and testing, and into full-scale production in support of initial build and continuing maintenance and repair.

WVA has manufacturing responsibility for 20 cannons[4] of which 7 to 8 are active. The arsenal has the national procurement and product assurance mission for all cannon systems, whether originally manufactured at WVA or elsewhere. Some cannon components must be produced internally at WVA because capable outside vendors can not be identified, while some raw castings and forgings must be acquired from outside sources because internal capabilities do not exist. WVA is a leader in precision deep-hole boring and rifling operations.

For the M256 tank gun (the 120-mm gun on the M1A1/M1A2 tank), components that must be manufactured organically include the ring, block, and tube. Many other components are procured from outside the arsenal and, in general,

[3]This is in contrast to the depots, where manufacturing is undertaken only to support the primary mission of maintenance and repair of fielded systems.

[4]WVA manufactures cannons of guns, howitzers, mortars, and recoilless rifles. A cannon is a complete assembly of the barrel of an artillery piece. It consists of a breech mechanism, firing mechanism, tube, and muzzle. A gun is an artillery piece that fires a projectile on a flat trajectory with high velocity and long range. Howitzers fire projectiles at high trajectory, low velocity, and shorter range than guns. Mortars also fire at high angles but with lower velocity than howitzers. They are usually loaded through the muzzle. Recoilless rifles are medium-caliber cannons with no recoil mechanism.

the vendor share of cannon value is increasing.[5] Currently, of 256 part numbers in the M256 tank gun, 130 are manufactured at WVA. WVA personnel estimate that the process planning system contains 5,000 parts, of which approximately 3,000 are active.

The nature of cannon manufacture is changing as cannons evolve from purely mechanical systems to complex computer-controlled, electro-mechanical devices. To maintain the manufacturing capability to produce the latest generation of cannons, WVA recently completed a 10-year, $350 million renovation and modernization program. With the completion of this program, WVA operates 1,430 machine tools, of which more than 260 are CNC. Included in this inventory of machines is a $16 million flexible manufacturing cell in which parts are shuttled between workstations on automated guided vehicles (AGVs).

WVA also maintains a horizontal turning and boring machine with an 80-foot-long bed. This huge machine is believed to be the only piece of equipment in the world capable of producing and repairing the Navy's largest battleship guns. This machine represents one of DoD's truly unique manufacturing capabilities. Currently this machine is in the final stages of a multi-million-dollar modernization program that includes an upgrade to its CNC system.

In addition to metal cutting machine tools (e.g., CNC machining centers and turning centers) WVA operates equipment to perform the following: welding, composite filament winding and braiding, forging, heat treatment, electroplating and surface coating, painting and packaging, and precision tool and die making.

About 25 people perform engineering in support of these processes. Among the software the arsenal uses are AutoCAD, Pro/ENGINEER, and SmartCAM for computer-aided design and manufacturing, and CimIntelligence and MetCut for computer-aided process planning.

The arsenal is currently operating at a small fraction of its capacity. This is because of a significant decrease in demand its for weapon systems and because of WVA's mission to support surge requirements.

FCIM-Related Initiatives

Many of WVA's initiatives related to FCIM involve working with DLA and Army item managers to improve procurement support. These initiatives are described in the following subsections.

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[5]Although sourcing decisions are based on a variety of criteria (e.g., cost, capacity, lead-time) the arsenal accounting system requires full burdening of costs. This may contribute to inaccurate costing of internal operations and lead to incorrect make-or-buy decisions.

ENGINEERING MATERIAL DATABASE

Many materials in weapons systems that are 10 to 15 years old or older are difficult to procure or are not available today. Quickly determining the availability of the proper material or a suitable substitute is important in delivering replacement parts on demand.

WVA has contracted with Concurrent Technologies Corporation to develop an engineering material database for material availability and material substitution. A prototype database is currently being tested at WVA, with the intention to transfer it to other organic sites once the prototype is proven effective.[7]

ORGANIC AND VENDOR LEAD-TIME REDUCTION

WVA is working closely with the item managers for weapons systems it manufactures to determine order quantities and reorder levels. The key focus of these activities has been on reducing lead-times both for components produced at the facility and those that are outsourced.

To reduce internal processing lead-time and increase production flexibility, WVA has altered the layout of the facility, acquired new equipment to improve material flow, developed computer-aided process planning applications, and worked on machine tool setup-time reduction.

Lead-times for some castings and forgings are one year. Efforts to reduce this lead-time (and also the component cost) have included writing long-term blanket purchase agreements with vendors. With shorter and more accurate lead-time predictions, the item manager is better able to determine production rates that satisfy field requirements, with a minimum of inventory.

RAPID PROTOTYPING

WVA has invested more than $750,000 in a rapid prototyping cell. The sterolithography machine in that cell is used to make prototypes for verification of technical data packages and is being studied for production of molds for investment and sand casting. The casting applications have the potential to significantly reduce the lead-time and cost associated with the procurement of small cast components.[8]

REVERSE ENGINEERING

WVA has proposed the development of a reverse engineering technology center. With this facility, WVA would combine its expertise in rapid prototyping and reverse engineering with its manufacturing capabilities to provide DLA with comprehensive technical data packages that have been proven in the manufacture of actual parts. The intent is to develop the technical data (including procurement history, inventory, and material data) in advance of actual demand so that an accurate and complete package can be put out for bid more quickly when demands occur.[9]

OPEN-ARCHITECTURE MACHINE-TOOL CONTROLLER

WVA, the Air Force Wright Laboratory's Manufacturing Directorate, and the Defense Production Act Title III Program Office have awarded a $10.3 million project for establishing an open-architecture machine-tool controller to OASYS Group, Inc., of Naperville, Illinois. The goal of this project is to make open-architecture controllers commercially available, and WVA will serve as an evaluation and test site for prototype controllers. The project sponsors believe that open-architecture controllers will permit users to customize their machine control and thereby improve their manufacturing capabilities. As open-architecture controllers are likely to be microcomputer-based, they could dramatically change the price and performance standards of the control industry, which currently relies on proprietary hardware and software.

OASYS Group, Inc., is a consortium of private and public companies composed of Automated Precision, Inc. of Gaithersburg, Maryland; Bridgeport Machines, Inc., of Bridgeport, Connecticut; Cleveland Machine Controls of Cleveland, Ohio; Sensor Adaptive Machines Inc. of Windsor, Ontario; STEP Tools, Inc., of Troy, New York. This consortium will be supported by other machine and controller manufacturers and has formed a vendor base of 13 additional companies to provide hardware, software, and consulting services.[10]

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APPENDIX B

Private-Sector Case Studies

BOEING COMMERCIAL AIRPLANE GROUP

Background

LMI visited the Boeing Commercial Airplane Group, Customer Services Division, Spares Department, to collect comparative information on policies, practices, and performance of satisfying customer requirements for spare parts.[1] In particular, we were interested in Boeing's efforts to reduce spare-part cycle times (demand to shipment). Boeing is a recognized industry leader in customer service, has high customer expectations, and deals with products operating globally and often in harsh environments or with man-safe requirements. This information will provide a commercial counterpart by which the DoD can evaluate its practices and set improvement targets.[1]

In this case study, we present the key aspects of Boeing's spare parts operations. Where possible, we identify the level of business activity and measures of performance. Where Boeing practices differs from DoD's, we attempt to distinguish the two.

Customer Goals and Expectations

The goals of Boeing's Spares Department are to assume responsibility when an airplane cannot fly and to provide rapid response with a minimal inventory investment by the airline. The Spares Department has the same number of employees as in 1970, but the number of parts has grown from 50,000 to 4.6 million and annual orders have grown from 125,000 to nearly 1 million. The Customer Services Division, of which the Spares Department is a part, is on an equal par with all other manufacturing and sales divisions. The activities of the Customer Services Division are recognized as important in distinguishing Boeing in the competitive commercial aircraft industry.

Boeing supports almost 7,000 aircraft in service (models 707, 727, 737, 747, 757, 767, and soon the model 777) with 400 customers (DoD has almost the same number of aircraft in service). Slightly more than one-half of this fleet (53 per-

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[1]Boeing was also recently visited by a DoD Inventory Control Point Benchmarking Team, headed by Terry Trepal, Office of the Assistant Under Secretary of Defense, Material Distribution and Management Policy.

cent) is in service with foreign airlines, and 56 percent of the aircraft in service are no longer in production. A general terms agreement between Boeing and its airline customers covers lifetime support of Boeing aircraft. Boeing commits to product support for an airplane for as long as any airline in the world is flying one plane of that type (or five planes each for models 707, 727, and 737 versions 1 and 2).

The cost of ownership is a major issue with the airlines. Because airplanes are becoming more of a commodity, service and support has increased in significance. A Boeing rule of thumb is that every 10-day increase in spare parts turnaround increases the airlines' investment in spares by one-third.

Boeing does not maintain commercial aircraft; airlines do. In this respect, Boeing is analogous to DoD's prime contractors and the airlines perform the functions of DoD depots. These airlines, however, rely on Boeing for much more than spare parts, including technical data, initial provisioning, maintenance training, and technical support. When an airline buys a Boeing aircraft, the airline and Boeing are making a mutual commitment to maintaining that aircraft over its operating life. Boeing warrants aircraft and spare parts to conform to applicable specifications and to be free from defects in materials and workmanship, and from defects in design in terms of being state of the art at time of design. For example, Boeing replaced nose sections of Japan Airlines' model 747s after 15 years of service, when the problem was determined to be a design deficiency.

From a parts perspective, a Boeing aircraft comprises "Boeing proprietary" parts, "supplier proprietary" parts, and standard parts. Proprietary parts, whether made by Boeing or Boeing's suppliers, are those for which the manufacturer owns the technical (materials, design, and manufacturing) data. Industry practice is that airlines procure proprietary parts from the original source. In contrast with DoD, airlines do not attempt to procure technical data from Boeing, do not reverse engineer, and do not generally "break out" the procurement of spare parts for the sake of competition. The only parts that airlines tend to buy competitively are standard parts or proprietary parts for which a number of suppliers offer form, fit, and functional equivalents.

Boeing's ultimate customer is the airline's engineer or line mechanic. Under Boeing's warranty, a demand is not satisfied when Boeing ships the order, but rather when the spare part is installed. To increase service to these customers, a Boeing customer account manager is assigned to each airline, providing a single contact for the airline. Airlines also have electronic access to Boeing: they can request quotes, check part availability, order parts, check the status of orders, and get shipping details — all on-line.

Technical Data

Boeing's technical drawings are stored in its Reference Engineering Data Automated Retrieval System (REDARS). REDARS is a technical library of raster-based images and is analogous to DoD's Digital Storage and Retrieval Engineering Data System (DSREDS) and Engineering Data Computer Assisted Retrieval System (EDCARS). REDARS images can be printed but cannot be changed without changing the original drawing and rescanning it. New aircraft (starting with model 777) are designed using three-dimensional CAD software (the CATIA package) and are stored and accessed separately from REDARS.

Boeing's parts catalog is published by Continental Data Graphics (CDG) in southern California. CDG also publishes for McDonnell Douglas and Mack Truck. Boeing's catalog is available in paper, microfilm, and CD-ROM. CDG takes raster images from Boeing (out of REDARS) in orthogonal view and changes them to isometric view.

The pedigree of parts is important and Boeing discourages airlines' use of unapproved parts. Configuration control is done via source-control drawings. If a vendor makes a change that affects form, fit, or function, the vendor must change the part number and notify Boeing. This activity is similar to the configuration management and control required by DoD.

Boeing has an internal improvement effort called Define and Control Airplane Configuration (DCAC). In terms of level of effort, DCAC is bigger than the model 777 aircraft development program and is the biggest Boeing corporate undertaking in 25 years. DCAC is an effort to stratify and streamline the configuration management of airplane models, from one individual plane to the next. To illustrate the need, there are five configurations for lights on model 737 landing gear. Still 90 to 95 percent of an airplane is common to other airplanes of that model. DCAC is defining three levels of parts:

1. Standard items from plane to plane

2. Items that have been installed on a previous plane

3. New designs (move to category 2 after the first installation).

Spares Service and Inventory

The spares business at Boeing is divided into two broad components: initial provisioning and sustainment. Boeing's basic products are "gliders," to which the airlines specify seating, avionics, and engine configurations. Boeing works with the airlines to develop a recommended spare-part list for initial provisioning. Initial provisions are based on fleet size, utilization, and the airline's repair capability ("line stations") and are determined by elaborate models (130 parameters). Boeing will repurchase any initially provisioned spares that are not used within five years.

We shall focus on the spares that are provided for sustaining fielded aircraft, as this is the part of Boeing's business that is analogous to our depot study. Orders for Boeing spare parts are received by Aircraft on Ground (AOG)

Operations and are classified into one of four priorities. Table B-1 describes those priorities and the portion of orders falling in each. Note that more than half of all orders are AOG or Critical. We address "normal lead-times" under "Manufacturing Capability" on page B-8.

Table B-1.
Priority Classifications for Boeing Spare Parts

Priority	Description	Time in which Boeing advises customers of action taken	1994 shipment breakdown
AOG	Aircraft on ground (requires tail number)	4 hours	18.8%
Critical	Imminent AOG or work stoppage	24 hours	38.1%
Expedite	Parts required in less than normal lead-time	7 days	12.8%
Routine	Parts required in normal lead-time	15 days	30.3%

Boeing's AOG Operations receives 2,600 to 2,800 requirements per day. In 1994, these totaled 879,000 spare-part orders across all priorities, of which 504,000 were classified as AOG or Critical.[2] The portion of total requirements that are classified as AOG/Critical has increased from 46 percent in 1990 to nearly 60 percent in 1994. AOG Operations satisfies its requirements for parts from four sources: inventory maintained at distribution centers located around the world, in-house rapid manufacturing capability, suppliers; and in-house production inventory. The percentage of AOG/Critical requirements satisfied from each of these sources is listed in Table B-2.

Table B-2.
How Boeing Satisfies AOG/Critical Spare-Part Orders

Source	Portion of orders
Distribution center inventory	70%
Boeing manufacturing	15%
Suppliers	10%
Boeing production inventory	5%

[2]Boeing's AOG/Critical customer service operation operates every day, around the clock.

In the remaining sections, we briefly describe these sources. Of particular interest to our study is the 15 percent of orders that must be met by Boeing manufacturing.

Distribution Centers

Currently, 4.6 million part numbers reside in Boeing's Sales Order Nonstop Inventory Control (SONIC) database, which can be queried to obtain stock availability at all of the Regional Distribution Centers.[3] Only a fraction of these items have had demand in the past 5 years and fewer still are in spare-part inventory at Boeing's one central, and several regional, distribution centers. Table B-3 shows how many part numbers are managed and gives approximate spares inventory levels. Note that several of the groups have overlapping definitions.

Table B-3.
Number of Part Numbers and Value of Inventory in Boeing's SONIC Database

Category	Number of part numbers	Value (billions of dollars)
In SONIC database	4.6 million	(unknown)
Active within last 5 years	700,000 to 800,000	(unknown)
Total spares inventory	400,000	About 5.0
In primary inventory	160,000,	About 1.4
"Planned" parts	100,000	(unknown)
"Unplanned" parts	60,000	(unknown)
In secondary inventory — "112 account," left over from production	240,000	About $3.6
In spares catalog, subset of "planned" parts	76,000	(unknown)

The total spares inventory is valued at $5 billion. Airlines carry additional inventory, for example, $1.5 billion at Delta and $1 billion at Lufthansa (both include engines, which are not in Boeing's inventory). Boeing is working with major airlines to reduce the airlines' inventory and lead-times. Since 1990 total spares inventory has been reduced from 453,000 to 400,000 part numbers and the value of primary inventory (160,000 part numbers) in stock has been reduced to $1.4 billion from more than $2.0 billion.

[3]About 60 percent of Boeing's customers avail themselves of direct access to the SONIC database. In a new initiative, Boeing intends to route on-line customer orders to the database, where a call for a valid part number will result in the issuance of an online order direct to the factory.

Boeing employs 68 people in inventory management, including 45 parts planners, managing the primary inventory mentioned previously. The primary inventory consists of "planned" and "unplanned" items.[4] Spares are "planned" because of activity due to historical sales, initial provisioning, or special programs (such as planned refurbishments).

Eighty-eight percent of orders to the distribution system are satisfied from planned parts inventory. A subset of the 100,000 planned parts is catalog parts. Spares catalog parts "are normally available for routine shipment in accordance with each customer's specific instructions, within 10 days after receipt of purchase order."[2]. Parts formerly classed as "planned," but with little sales history and no anticipated requirements, are not procured again and, if inventory remains, will be classed as "unplanned."

Boeing's central warehouse is the Seattle Distribution Center (SDC). All planned parts are carried there. In addition, regional distribution centers carry a subset of Seattle's planned parts for which sufficient regional demand exists. General guidelines are, if two orders from two customers are received within two years for new aircraft, the item will be stocked (i.e., planned) at SDC; similarly, if four to five orders are received within 1 year for old aircraft, the item will be stocked. An item will be stocked at the appropriate regional distribution center when two sales to one customer within 1 year are recorded. At distribution centers minimum stocking quantities are maintained at 60 days' demand at confidence level of 90 percent.[5] Table B-4 lists Boeing's warehouses, the number of part numbers (line items, not pieces) they store (planned and unplanned), and approximate inventory values. The difference between the number of part numbers at SDC and the total part numbers in the distribution system is the number of unplanned part numbers at the regional centers and lease items (described below).

Boeing's SDC has instituted a next-day shipment program wherein orders that can be satisfied from inventory are shipped the day after order receipt. Table B-5 shows the distribution of order satisfaction time for planned parts. The data in the table imply that most orders of all priorities (not just AOG and Critical) are being satisfied in one day.

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[4]The term "stocked" part is a misnomer. These are parts whose demand is forecasted, for which inventory policies (order quantities and safety stocks) are calculated, and for which warehouse inventory is replenished. Many other parts may be in stock in the warehouse but are not being forecasted or replenished, or actively managed.

[5]The importance of the transportation process to the overall delivery time of a part to the customer's end user is illustrated by Boeing's estimate of one day for Boeing to get a part to the customer's location and three days for the customer to place the part in the hands of the ultimate end user.

Table B-4.
Boeing Stock Sites

Distribution center	Number of primary part numbers	Inventory value (millions of dollars)
Seattle	142,000	1,135
Los Angeles	380	Not available
Atlanta	47,000	93
London	45,000	86
Brussels	32,000	43
Singapore	19,000	22
Beijing	15,000	Not available
Total	160,000	1,400

Table B-5.
Order Satisfaction Time for Planned Parts

Cumulative portion of orders satisfied	Number of days
94%	1
97%	8
100%	20

Boeing has established a special category of items called "insurance spares" or "lease items." These are stocked in Seattle, Los Angeles, and London. Insurance spares are expensive items, with long lead-times, that don't wear out but when damaged are generally repaired rather than replaced. Major categories are landing gear doors, control surfaces, and engine cowlings. Insurance spares are not stocked by the airlines and are leased to the airlines while the original part is being repaired. Typical lease terms are a daily rate equaling 1/365th of full part cost.

Stock levels in the warehouses are determined by demand forecasts and by inventory policy calculations. Boeing uses several approaches to forecasting to accommodate different demand patterns, e.g., trends over time and long periods of no demand. Boeing forecasts on the basis of its sales data, since it has no visibility into airline consumption. One area of improvement would be for Boeing to capture spares consumption data and use it to forecast. Boeing then feeds its forecast into inventory policy calculations. The overall approach is a reorder-point, reorder-quantity inventory system with safety stock, but Boeing is experimenting with cyclic (or periodic) ordering.

Seattle Distribution Center

The main Boeing spares warehouse is SDC, located at the Seattle/Tacoma airport. SDC occupies 702,000 square feet and employs about 300 people. This distribution center makes 500,000 shipments per year, with fewer than 1 percent material returns. It offers next-day shipment (order today, ship tomorrow) for material on hand. SDC was located at the airport because it frequently ships by air and because traffic congestion in the Seattle area was affecting trucking times.

AOG orders get priority. When an AOG pick list is printed, orders on it are picked immediately or before non-AOG orders. Each day, multiple orders from an airline or location are consolidated for shipment. Orders are sorted on the first shift and packed on the second. Orders are staged in a carousel. Sorting takes place on one end; packing from the other.

Warehouse storage is divided into three areas: "small parts," "high-bay," and "bulk." These areas house about 100,000, 300,000, and 2,500 parts, respectively. The layout is efficient, with overhead conveyors to transport goods from pick areas to staging areas. All items are tracked by computer from receipt to shipment.

An important aspect of SDC operations not often associated with warehousing is package engineering. Packaging of large spares, e.g., rudders, is critical to their safe storage, handling, and transport. For the model 777, SDC uses CATIA to design the package, which is then constructed primarily from wood. Package engineers work from paper prints or directly from the part for pre-777 aircraft packages.

Manufacturing Capability

To support its planned inventory, the Customer Services Division draws on the capabilities of 12 Boeing manufacturing facilities located in the United States and Canada. These facilities produce 96,500 planned parts. In 1994 the cumulative average reorder lead-time for these items was 247 days, with, for example, Boeing of Georgia supplying 1,515 parts with an average lead-time of 353 and Everett supplying 10,048 parts with average lead-time of 205 days.

When a planned item is out of stock, these facilities respond in slightly more than 9 days, on average, to Critical requirements and 7.5 days on average to AOG requirements. Currently, requirements for AOG/Critical Boeing manufactured parts total 1,500 items per week (compared with the 1,000 AOG/Critical parts purchased from approximately 4,400 outside suppliers). Not all AOG/Critical requirements are for planned items. A number of these requirements are for others of the 4.6 million Boeing parts in the SONIC database. These requirements are classed as machine, sheet metal, or nonduct weld. Machine items are processed in the Emergent Manufacturing Facility (EMF) and sheet metal items are processed at the Sheet Metal Facility.

Emergent Manufacturing Facility

The EMF is located in Auburn, Washington, and is also referred to as the "Emergency Manufacturing Facility." It occupies about 440,000 square feet and employs 350 people, including 280 hourly personnel (46 people doing machining) and 70 salaried staff (mostly engineers and buyers). The EMF can make almost any metal part, from aluminum to stainless steel, including hard metals. In addition to machining, typical processing steps include presswork, cleaning, testing and inspecting, heat-treating, and painting or anodizing.

The EMF serves four major customers: Renton, Everett, 777 manufacturing plants, and Customer Services Division. The plant was primarily built to handle production for spares priorities AOG and Critical. Orders with these priorities are worked seven days a week. The facility, however, also does work for new aircraft production and for planned inventory. Spares production represents about 35 percent of total volume. AOG/Critical work, mostly one-piece lots, represents about 15 percent of total volume.

This approach to facility sizing represents a dramatic departure from DoD's approach to depot workloading. The depots nominally produce only those parts that cannot be obtained from the private sector. Therefore, depot manufacturing levels fluctuate greatly and capacity is underused. Boeing "level-loads" the EMF by supplementing spares orders with normal production orders. AOG/Critical spare-part orders, when they arrive, assume top priority, even to the extent that production setups are torn down to make way for spares orders.

The EMF uses "virtual cells," teams of people who move to where the work is, to help with rapid throughput. These teams work a job from start to finish. People can rotate from team to team, as capability and capacity requires. Some skills are critical: "Unique or critical skills will require coordination of work into and out of these processes to maintain a smooth flow of work and allow for load control within these areas. Unique skills are identified as joggle, shot peen, roll form, profile mill, numerically controlled drill press, punch press, brake press, spindle shaper, and CATIA operations."[3]

Above-the-shop-floor activities — manufacturing engineering, planning, and scheduling — take about 2 days on average and the flow time from material receiving to final processing averages 4.9 days; total production flow time is, therefore, 6 to 7 days for AOG/Critical requirements. About 1,000 orders are open at a given time in the EMF, and 300–350 jobs per week are completed. (By these statistics, the average job is open for 3 weeks). A large lot is considered to be one of more than 5 parts. By contrast, the Auburn facility supplies 9,209 planned parts (of lower priority) with an average lead-time of 233 days.

Sheet Metal Facility

Boeing also operates a sheet metal manufacturing facility in Auburn (which represents a consolidation of five formerly separate facilities). The facility occupies about 848,000 square feet and employs about 800 people. It processes 7.5 million parts per year on two shifts. The sheet metal facility has three main process areas: flat-sheet, extrusion, and miscellaneous (e.g., stretch).

A major focus at the sheet metal facility has been lead-time reduction. Boeing has reduced average lead-times there from 50 days to 7 days. The current goal is 5 days. One technique was to put ancillary equipment (e.g., saws) into normal processing cells to reduce material transit time and to provide all of the tools necessary to complete the entire part. About 25 percent of all sheet metal parts are spares.

Supplier Support

Airlines buy major spares from Boeing's suppliers directly. Thirty-six people work in Boeing's supplier support department assisting the airlines in buying supplier parts.

Boeing works with the suppliers to alert them to potential demand and to ensure high-quality service. The company has 4,100 domestic and 290 foreign suppliers. Boeing purchases, rather than manufactures, 70 percent of a typical plane's parts, representing 80 percent of the plane's value. Boeing tends to use one or only a few sources for specific parts requirements. Boeing gives contractors forecasts to help stabilize the vendor's workload. Boeing does not generally guarantee levels of business (e.g., monthly minimums); the contractor is basically getting the expectation of business.

A product support agreement formalizes the relationship between Boeing and its suppliers. The agreement establishes general product support (and a commitment of the supplier as long as there is at least one aircraft of any model using the supplier's parts in service anywhere in the world), provisioning and spares lead-time goals, ground-support equipment requirements, data requirements, and training support. The agreements also cover inventory policy, 24-hour AOG support, and warranty coverage. No specific incentives apply to lead-time goals, other than to continue to get business from Boeing. Boeing conducts on-site supplier surveillance to ensure compliance.

Boeing performs benchmark studies with other companies, e.g., HR Textron, HP Worldwide, and United Technologies/Hamilton Standard. It also works with suppliers to develop metrics for meeting customer expectations and for processes to collect data for those metrics. Boeing would like to, but does not currently, get data from airlines on spares delivery performance of Boeing's suppliers.

Commodity Contracting

One Boeing strategy, called commodity contracting, offers a model by which the government might get shorter lead-times and lower costs from its suppliers.

The commodity contracting strategy involves identifying potential parts families from Boeing's commodity code database. Each family is then sole-sourced.

Boeing has developed the part families listed in Table B-6, each of which is sole sourced.

Table B-6.
Commodity Contracting Part Families

Family	Number of parts
Stamped sheet metal	804
6"–13" turned	248
Milled/Turned	720
Nonmetal turned	253
Metal milled	4,166
Spars, chords	280
Formed sheet metal	4,100
Major assemblies	2,507

Under commodity contracting, spares performance expectations are now contractual obligations. Reorder lead-times for these parts have been reduced by between 43 percent and 57 percent (we were given specific examples that are marked "BOEING LIMITED"). The benefit for the supplier is more stable work, which facilitates employment stability and capital-improvement decision-making.

Summary

Boeing's Spares Department focuses on giving superior service with long-term commitments to both customers and suppliers. Its operations offer several lessons for DoD. First, Boeing emphasizes understanding who the customer is and what support service is required. A significant portion of Boeing's pay to its personnel is merit based, and the focus is clearly on satisfying the customer. Second, Boeing has only four priority levels (soon to be reduced to three as AOG/Critical will be merged) for orders and concentrates on giving essentially one-week service on all items in the top two priorities, even if those items must be manufactured. Third, Boeing has established an internal manufacturing operation expressly to satisfy spare-part orders, but runs the operation efficiently by level-loading it with lower-priority spares and normal production orders and by using modern manufacturing philosophies of concurrent operation, continuous-velocity operation, and flexible work teams. Fourth, Boeing has developed a major program of design configuration control and digital data generation that will be used throughout the company's own operations and in its interactions with its vendors for parts supply. Finally, Boeing is getting rapid turnaround on orders with its vendors by establishing a commodity contracting program that awards work for a family of parts to a single source, with a program that will reduce the company's number of suppliers from several thousand to several hundred.

KOLAR MACHINE, INC.

Kolar Machine, Inc., in Ithaca, New York, is a machine shop with 55 employees that specializes in the production of small batches of precision metal parts for the electronics, computer, and aerospace industries.[4] This market segment is highly competitive (some 4,000 machine shops of various size and capability operate in the United States), yet Kolar has continued to grow at the rate of one or two new numerically controlled machine tools per year for the past decade and currently operates a total of 20 numerically controlled machines. Their main customers, General Electric, IBM, Kodak, and Universal Instruments, are located near Ithaca, New York, but Kolar has sales representatives covering the East Coast.

Business Overview

Kolar typically receives a bid request package that contains part blueprints (which include detailed part specifications, material and processing requirements, and coatings) and ancillary materials that include delivery date, production quantity, customer contact, and any special terms.

A typical job that Kolar will bid on requires precision machining of a casting and subsequent coating or painting (though sometimes the casting is coated before it is machined). Recently, Kolar has successfully bid on work requiring assembly of machined components, and this may become a larger portion of its business. Kolar uses a number of outside vendors for castings and coatings and other special operations, and it has a small fleet of trucks to move material between itself, its vendors, and its customers. Production quantities of 10 to 50 units are common, but the company has undertaken production of single prototypes and batches of 2,000.

Lead-times from receipt of order to delivery are largely dependent on casting availability that averages 4 to 6 weeks (but can be up to 12 weeks or more for some alloys or in robust economic conditions). Kolar's quoted response times are usually 6 to 8 weeks. This is unacceptable for some customers in the electronics industry, and one company has signed a long-term purchase agreement with Kolar with the requirement that orders placed on Monday will be filled the following Monday.

To meet this constraint, Kolar now carries an inventory of the castings. These are held in their lowest-value form (as raw castings with a value of approximately $150 per unit) and no machining or assembly is performed until an order is received. Sales under this contract range from 20 to 30 units per month.

Kolar operates with a fully staffed first shift and a skeleton manufacturing crew of machine operators and a supervisor on the evening shift to handle peaks in demand. Most of Kolar's production equipment is Japanese (Mori Seiki, Matsuura, Okuma, and Nakamura-Tome, and some older Bridgeports), and all have Fanuc controllers. Their coordinate measuring machines (CMMs) and inspection equipment is American (Browne & Sharpe, Federal, and Starrett), and Kolar's computer hardware and software is American. The company uses cutting tools of most manufacturers, including Kennametal, Carboloy, and Valenite.

Manufacturing Operations

Kolar's precision shop is primarily composed of numerically controlled equipment, including 18 vertical and horizontal machining centers and 2 turning centers. All of these machines have automated tool changers, and many of the horizontal machining centers have two pallets for advance setup. The operation of this equipment requires skilled workers. Kolar has recognized the cost of recruiting and training such a work force and attempts to retain them through good management practices and generous (for the local economy) pay and benefit packages. Machine operators earn from $10 to $15 per hour, and Kolar's work force is nonunion. The machine operators are responsible for machine setup and tear-down, tool buildup and tear-down, work-piece loading and unloading, numerical control (NC) program test out, most work-piece inspection, and basic machine maintenance.

The layout of the equipment is random and is an indication of the order in which the equipment was acquired and building additions were constructed to house the equipment. Although many of Kolar's horizontal NC machining centers have four-axis capability, an increasing percentage of the company's work requires multiple setups and runs on two or more machines. To address this, Kolar has begun reorganizing its facility layout to improve material flow and operator utilization. For example, a pair of vertical milling machines have been located facing each other so that a single operator can monitor both machines.

For its repeat business, Kolar has invested heavily in equipment to minimize setup time and improve delivery response. The company acquired a horizontal machining center with a 70-station tool magazine and a 10-pallet carousel so that fixtures for up to 40 of the parts most frequently reordered could remain permanently set up. Kolar now has sufficient experience with this family of parts that, if demand is great enough, the machine will be run unattended through the third shift.

Kolar is not solely an NC shop. An estimated one-third of its revenues are generated from manual equipment. For example, Kolar maintains a bank of 12 drill presses that remain set up with the most commonly used drills and taps for rapidly completing these operations in support of operations completed on its numerically controlled machines.

Another portion of Kolar's operations is dedicated to the largely manual fabrication of stainless steel plate and sheet for assembly by the Hi-speed Checkweigher company into food-processing and -handling machinery. Each of these machines is custom made to Hi-speed's customer specifications. Kolar's activities consist of shearing and bending plates to size and drilling and tapping holes for mounting brackets, motors, and pulleys. Although this process can be automated, the economics of doing this are not favorable. Automation will likely increase the capital invested, with no reduction in lead-time, operating expenses, or improvement in quality.

Engineering and Quality

The manufacturing floor is supported by manufacturing engineering and quality departments. The manufacturing engineering department is engaged in the design of tooling and fixturing and generation of NC programs. For these purposes, Kolar runs SmartCAM NC programming software on two Sun workstations.

Because of the close proximity of the engineering office to the manufacturing floor, the engineering staff and machine operators frequently communicate during tooling and fixture design and NC programming. This, combined with the engineers' familiarity with the individual machine characteristics, ensures that high-quality NC programs are released to the floor. VeriCut machining simulation software for tool-path verification is used as a final check of the NC program before it is downloaded over a local-area network to the machine tool. Production runs are usually so small that statistical process control techniques cannot be employed. Complete first-part inspection combined with constant operator monitoring is used to ensure the delivery of quality parts.

Kolar's interface with the customer is slowly moving toward an electronic medium, but currently the engineers usually receive blueprints that contain part specifications, from which they work. In responding to a request for quotation, Kolar generates a complete NC program so that the company has an accurate measure of the machine time required to produce the part. Kolar's pricing is based solely on machine hours.

Manufacturing Management

To better manage its operations, Kolar is in the process of installing a computer-based management system. The first components installed were those to manage job costing, invoicing and accounts receivable, purchasing and accounts payable, and payroll and inventory. These automated processes replaced a variety of manual activities and noninterfaced software packages. This change should improve the accuracy and timeliness of report generation. Currently, Kolar is installing the system components for scheduling, manufacturing tracking, and preventive-maintenance.

Investment Strategy

Kolar's management believes growth is likely to come in its precision NC operations as its customers, and many other large manufacturers, choose to close high-cost manufacturing facilities and outsource machining operations. To position itself to take advantage of this changing market, Kolar has chosen controlled, revenue-financed growth rather than growth through acquisition that may leave it financially weakened and unable to survive the next recession.

Kolar recently acquired another facility to which it will move its manufacture of food-processing equipment. This move will provide about 50 percent more floor space at its existing facility for expanding NC and supporting operations. Current plans call for preparations to add numerically controlled machines at a rate of one or two machines per year (a $500,000 to $750,000 investment) as business opportunities develop.

Small shops working with local banks, such as Kolar, do not generally have the resources to make investments in facilities, equipment, or people unless they get near-term returns on these investments or special circumstances arise. Kolar management is constantly following the market and its competitors. Although it has thus far chosen not to acquire competitors (or operations that customers have targeted for closure), it has purchased operating assets at bankruptcy sales. Even with the market's growth potential, Kolar still finds it to be intensely competitive and is forced to closely monitor company investments and expenses.

References

[1] Interview with Messrs. Clyde Akiyama and Larry Strunk and with staff of the Boeing Commercial Airplane Group, Customer Services Division, Spares Department, 20–21 March 1995.

[2] The Boeing Company, *1994 Spare Parts Price Catalog*, Boeing Commercial Airplane Group, 1994.

[3] The Boeing Company, *Emergent Manufacturing Facility Customer Based Teams Operation Information Document*, 1 December, 1993.

[4] Interview with Mr. Dan Liguori, President and Owner, Kolar Machine, Inc., 25 February 1995.

APPENDIX C

Joint Engineering Data Management and Information Control System Sites and Network Issues

In the sections below we list the sites where the Joint Engineering Data Management and Information Control System (JEDMICS) has been installed and where it is slated to be installed. We also present a brief technical discussion of the computer network issues associated with JEDMICS.[1]

INSTALLED SITES

U.S. Navy, Naval Ordnance Station, Louisville, Kentucky, March 1991

U.S. Navy, Portsmouth Naval Shipyard, New Hampshire, January 1992

U.S. Navy, Mare Island Naval Shipyard, Vallejo, California, March 1992 (now closed)

DLA, Defense General Supply Center, Richmond, Virginia, April 1992

U.S. Navy, Ships Parts Control Center, Mechanicsburg, Pennsylvania, July 1992

DLA, Defense Construction Supply Center, Columbus, Ohio, July 1992

U.S. Navy, SPAWAR Technical Data Center, Portsmouth, Virginia, August 1992

DLA, Defense Electronic Supply Center, Dayton, Ohio, October 1992

U.S. Navy, Marine Corps Logistics Base, Albany, Georgia, January 1993

DLA, Defense Industry Supply Center, Philadelphia, Pennsylvania, February 1993

U.S. Navy, NAVAIR Technical Support Facility, Philadelphia, Pennsylvania, March 1993

U.S. Navy, Puget Sound Naval Shipyard, Bremerton, Washington, August 1993

U.S. Navy, Norfolk Naval Shipyard, Portsmouth, Virginia, October 1993

U.S. Army, Missile Command, Redstone Arsenal, Alabama, November 1993

U.S. Navy, Pearl Harbor Naval Shipyard, Hawaii, February 1994

U.S. Navy, Naval Surface Warfare Center, Port Hueneme, California, March 1994

U.S. Navy, Navy Air Warfare Center-Training Systems Division, Orlando, Florida, May 1994

U.S. Navy, AEGIS Destroyer Planning Yard, Bath, Maine, June 1994

U.S. Army, Letterkenny Depot, Chambersburg, Pennsylvania, August 1994

U.S. Army, Anniston Depot, Alabama, October 1994

U.S. Army, Tobyhanna Depot, Pennsylvania, October 1994

U.S. Army, Corpus Christi Depot, Corpus Christi, Texas, October 1994

U.S. Army, Red River Depot, Texas, November 1994

U.S. Air Force, Robins AFB, Warner-Robins, Georgia, November 1994

U.S. Navy AEGIS Cruiser Planning Yard, Pascagoula, Mississippi, January 1995

U.S. Navy, Naval Aviation Depot — North Island, San Diego, California, April 1995

U.S. Army, Armaments, Munitions, Chemicals Command, Rock Island, Illinois, May 1995

U.S. Air Force, Tinker Air Force Base (AFB), Oklahoma City, Oklahoma, June 1995

U.S. Army, Communications and Electronics Command, Ft. Monmouth, New Jersey, July 1995

PLANNED SITES

U.S. Army, Missile Command, Redstone Arsenal, Huntsville, Alabama, November 1995

U.S. Air Force, Ogden Air Logistics Center, Hill AFB, Utah, 1995

U.S. Air Force, Sacramento Air Logistics Center, McClellan AFB, California, 1996

U.S. Army, Aviation & Troops Support Command, St. Louis, Missouri, 1996

U.S. Air Force, San Antonio Air Logistics Center, Kelly AFB, Texas, April 1996

U.S. Army, Picatinny Arsenal, Dover, New Jersey, August 1996

U.S. Army, Tank-Automotive and Armaments Command, Warren, Michigan, July 1996

U.S. Navy, Ship Repair Facility, Yokosuka, Japan, June 1996

U.S. Navy, Naval Aviation Depot — Cherry Point, North Carolina, November 1996

U.S. Navy, Naval Air Warfare Center — Warfare Division, Pt. Mugu, California, January 1997

U.S. Navy, Naval Aviation Depot — Jacksonville, Jacksonville, Florida, date to be determined

U.S. Navy, Naval Aviation Technical Services Facility, Pensacola, Florida, date to be determined

U.S. Navy, Naval Air Warfare Center, Aircraft Division, Lakehurst, New Jersey, date to be determined

U.S. Navy, Naval Air Warfare Center, Aircraft Division, Indianapolis, Indiana, date to be determined

U.S. Navy, Naval Aviation Depot — Alameda, California, date to be determined

U.S. Navy, Naval Aviation Depot — Pensacola, Florida, date to be determined

U.S. Navy, Naval Aviation Depot — Norfolk, Virginia, date to be determined

NETWORK ISSUES

JEDMICS sites interface with the Defense Data Network (DDN), also known as the Military Network (MILNET), through JEDMICS software, while DDN is the interface for communicating between repositories and remote sites.[2] The Defense Information Systems Agency (DISA) has been instituting a new Defense communications network identified as Defense Information Systems Network (DISN) or Unclassified but Sensitive (N-level) Internet Protocol Router Network (NIPRNET). This network is an Internet Protocol (IP) routed network requiring router access and IP addresses for the workstations needing to communicate through this medium. The classified part of DISN is called Secret Internet Protocol Router Network (SIPRNET). DDN is currently scheduled to be phased out by October 1995. The phase-in implementation of DISN will occur simultaneously during the phase-out of DDN. This schedule is now on hold, and the target completion date is unknown. During the phase-out of DDN and phase-in of

DISN, the Joint Interconnection Service (JIS) will provide connectivity between the two networks. It will be used to connect the DDN subscribers to DISN subscribers until the host systems have been rehomed to IP routers.

Currently the military services are using the DDN, their own wide-area networks and leased lines to transmit information for their respective systems: Army — Digital Storage and Retrieval Engineering Data System (DSREDS); Air Force — Engineering Data Computer-Assisted Retrieval System (EDCARS); Navy — EDMICS and JEDMICS; and DLA — JEDMICS. Two organizations currently have remote users with access to their JEDMICS data. The remainder of the organizations use their respective military service system (DSREDS, EDCARS, EDMICS) to transmit engineering drawings. EDCARS is accessed through DDN, Air Force T1 Network (AFNET) and leased lines. DSREDS (which is scheduled to be turned off by the end of 1995 after JEDMICS has been deployed to all remaining sites) is accessed through DDN and leased lines. EDMICS is accessed through DDN and Navy T1 Network (NAVNET) and leased lines. Access to these systems is provided through Intergraph software and AT&T Image Display and Access Software (IDAS). AFNET and NAVNET are the router-based networks of the Air Force and Navy, respectively. These networks will provide connectivity to NIPRNET. Intergraph has developed for the government the Intergraph Imager software, which links directly to DSREDS and EDCARS databases, as does AT&T's IDAS. Intergraph is working on a version that will also link directly to the JEDMICS database.

References

[1] Planning Research Corporation, *JEDMICS Summary Schedule*, April 1995.

[2] Department of Defense, *JEDMICS Telecommunication Plan*, Engineering Data Management System Program Management Office, Redstone Arsenal, 28 April 1995.

APPENDIX D

Components of ISO 10303, *Standard for the Exchange of Product Model Data*

This appendix contains reprints of "STEP on a Page," a summary of International Organization for Standardization (ISO) 10303, *Standard for the Exchange of Product Model Data,* prepared by the U.S. Product Data Association.

Rev. 7.20.95

STEP on a Page

ISO 10303

(For an explanation of diagram, see opposite page)

APPLICATION PROTOCOLS

I	201	Explicit Draughting
C	202	Associative Draughting
I	203	Configuration-Controlled Design
C	204	Mechnical Design using Boundary Representation
C	205	Mechanical Design Using Surface Representation
	206	Mechanical Design Using Wireframe (discontinued)
C	207	Sheet Metal Die Planning and Design
W	208	Life Cycle Product Change Process
W	209	Dgn Thru Anal of Composite & Metallic Structures
C	210	Electronic Printed Circuit Assembly: Dgn & Mfg
W	211	Electronic P C Assy: Test, Diagnostics, & Remanuf
C*	212	Electrotechnical Design and Installation
C	213	Num Control (NC) Process Plans for Machined Parts
W	214	Core Data for Automotive Mech Design Processes
W	215	Ship Arrangement
W	216	Ship Moulded Forms
W	217	Ship Piping
W	218	Ship Structures
	219	Dimension Inspection (discontinued)
W	220	Printed Circuit Assembly: Mfg Planning
W	221	Process Plant Funtional Data & its Schematic Rep.
W	222	Design-Mfg for Composite Structures
W	223	Exg of Dgn and Mfg. Product Info for Cast Parts
C*	224	Mech Parts Def. for P.Plg. Using Form Features
W	225	Strct Bldg Elements using Explicit Shape Representation
W	226	Ship's Mechanical Systems
W	227	Plant Spatial Configuration
W	228	Building Services: HVAC
W	230	Building Structural Frame: Steelwork
O		Forged Parts
O		Multi-chip Modules
O		Process-Engineering Data

DESCRIPTION METHODS

I	1	Overview and Fund. Principles
W		Overview, Amendment 1
I	11	EXPRESS Lang. & Ref. Man.
C	12	EXPRESS I Lang. Ref. Manual
W	13	STEP Development Methodology

INTEGRATED INFORMATION RESOURCES

INTEGRATED APPLICATION RESOURCES

I	101	Draughting
A	102	Ship Structures
W	103	Electrical/Electronics Connectivity
C	104	Finite Element Analysis
C	105	Kinematics
A	106	Bldg Core Constr. Model
A		Parametric Capability
A		Software Functionality Mechanical

INTEGRATED GENERIC RESOURCES

I	41	Fundamentals of Product Description and Support
I	42	Geometric and Topological Representations
I	43	Representation Specialization
I	44	Product Structure Configuration
C	45	Materials
I	46	Visual Presentation
C	47	Tolerances
	48	Form Features (discontinued)
C	49	Process Structure & Properties

IMPLEMENTATION METHODS

I	21	Physical File, Exchange Structure
		Working Format, Active Transfer
C	22	Standard Data Access Interface
		Knowledgebase
O		CORBA IDL 22 —> 23 Mapping
C	23	Early C++ (binding for #22)
C	24	Late C (binding for #22)
C	25	Late FORTRAN (binding for #22)

CONFORMANCE TESTING METHODOLOGY FRAMEWORK

I	31	General Concepts
C	32	Requirements on Testing Labs & Clients
C	33	Abstract Test Suites
C	34	Abstract Test Methods for Part 21
W	35	Abstract Test Methods for Part 22

Legend: Part Status

A=Approved to begin work
O=Prelim. Stage (Proposal —> approve NP ballot)
P=Proposal Stg. (NP circ. —> NP approval)
W=Preparatory Stg. (Working Draft devel —> CD reg.)
C*=CD for Comment (WD issue prior to CD registr.)
C=Committee Stg. (CD circ. —> DIS registration)
D=Approval Stg. (DIS circ. —> Int'l Standard registr.)
I=Publication Stg. (Int'l Standard approved & published)

◯=STEP Initial Release

STEP ON A PAGE

STEP on a Page shows the status of the STEP standard and reflects the developments and accomplishments that have transpired as of the last STEP ISO TC184 SC4 meeting held in Davos, Switzerland in May 1994. It provides a graphic summary of the progress of the STEP standard.

Status of STEP Parts

The twelve Parts that form the initial release of STEP are circled in the diagram.

Every Part shown in the *STEP on a Page* has its status shown beside it. The status designators vary from "A" (*Approved for Development* — the formative stage of development) to "I" (*International Standard* — the most advanced stage of development and standards acceptance). Question marks are placed beside Parts whose current status is unknown. Parts designated as "D" *(Draft International Standard)* and "I" are considered advanced enough to allow software vendors to write to them.

Architecture of STEP and *STEP on a PAGE*

STEP on a Page attempts to reflect the STEP architecture by grouping the STEP Parts into five main groupings — Integrated Information Resources, Conformance Tools, Description Methods, Implementation Methods, and Application Protocols.

From an architectural perspective, the Description Methods group forms the underpinning of the STEP standard, consisting of parts that describe the data modeling language that is employed in STEP and containing the definitions that are universal to the STEP standard. The Descriptive Methods group contains Parts 1, 11, and 12 and is the "mortar" used to construct STEP product data models. Parts in the Descriptive Methods group are numbered 1-19.

At the next level is the Integrated Information Resources group, the parts that contain actual STEP data models. These data models can be considered the building blocks of STEP. This group contains Parts that are"reusable" by application protocols (APs). Integrated Information Resources are sub-grouped into Generic Resources and Application Resources. Parts within Generic Resources are numbered in the 40s and are used across the entire STEP spectrum of APs. The other sub-grouping, application resources, is slightly more specialized in scope. Parts in this group can be utilized by the APs where applicable. The parts in the Integrated Information application Resources are numbered in the 100s. Parts in the resources groups are shareable across application protocols and promote AP integration and interoperability.

At the top level of the STEP hierarchy are the more complex data models used to describe specific product data applications. These parts are known as Application Protocols and describe not only what data is to be used in describing a product, but how the data is to be used in the model. APs are numbered in the 200s. The APs are analogous to systems or processes that utilize the lower-level integration information resources in well-defined combinations and configurations to represent a particular data model of an engineering or technical application. APs currently in use are the Explicit Draughting AP (AP 201) and the Configuration-Controlled Design AP (AP 203).

The Other STEP Groupings — Implementation/Conformance

The remaining STEP groupings are Implementation Methods (Part 2x series) and the Conformance Tools (Part 3x series). The Implementation Methods describe the mapping from STEP to formal languages used to implement STEP.

Conformance methods provide information on methods for testing of product conformance to the STEP standard, as well as providing guidance for creating abstract test suites, and delineating the responsibilities of testing laboratories. The diagram shows that Part 31, which describes the methodology for performing conformance testing, has been approved as an international standard. The STEP standard is unique in that it places a very high emphasis on testing and places these methods in the actual standard itself.

Not pictured in the diagram are the 12xx series of parts-abstract test suites. These test suites consist of test data that are used to test the degree of conformance of a STEP software product to the associated AP. Every AP is required to contain an associated abstract test suite. To obtain the particular number of the abstract test suite associated with an AP, one simply adds 1000 to the part number of the AP. For example, the abstract test suite associated with Part 203 would be Part 1203.

STEP on a Page was conceived and implemented by Jim Nell, NIST. *STEP on a Page* will appear in future issues of *the PRO Exchange* to keep readers apprised of the status of the STEP standard.

Origin: ISO 10303 Editing Committee

APPENDIX E

Glossary

ADC	=	Automated Document Conversion
AFNET	=	Air Force T1 Network
AGV	=	automated guided vehicles
ANSI	=	American National Standards Institute
AOG	=	aircraft on ground
ARLSS	=	Automated RAMP Logistic Support System
CAD	=	computer-aided design
CALS	=	Continuous Acquisition and Life-Cycle Support
CAM	=	computer-aided manufacturing
CDG	=	Continental Data Graphics
CECOM	=	Communications and Electronics Command
CIM	=	computer-integrated manufacturing
CNC	=	computer numerically controlled
DCAC	=	Define and Control Airplane Configuration
DDN	=	Defense Data Network
DESC	=	Defense Electronics Supply Center
DISA	=	Defense Information Systems Agency
DISN	=	Defense Information Systems network
DLA	=	Defense Logistics Agency
DoD	=	Department of Defense
DSREDS	=	Digital Storage and Retrieval Engineering Data System

DUSD(L)	=	Deputy Under Secretary of Defense (Logistics)
EDCARS	=	Engineering Data Computer Assisted Retrieval System
EDMICS	=	Engineering Data Management Information and Control System
EIA	=	Electronic Industries Association
EMF	=	Emergent Manufacturing Facility
FBMC	=	Feature-Based Manufacturing Center
FCIM	=	flexible, computer integrated manufacturing
GOCO	=	government-owned, contractor-operated
GPPE	=	Generative Process Planning Environment
IDAS	=	Image Display and Access Software
IGES	=	Initial Graphics Exchange Specification
IP	=	Internet Protocol
IPC	=	Institute for Interconnecting and Packaging Electronic Circuits
IPDE	=	Integrated Product Data Environment
ISO	=	International Organization for Standardization
JDMAG	=	Joint Depot Maintenance Advisory Group
JEDMICS	=	Joint Engineering Data Management and Information Control System
JIS	=	Joint Interconnection Service
MCC&QA	=	Manufacturing Cell Control and Quality Assurance
MILNET	=	Military Network
NAVSUP	=	Naval Supply Systems Command
NAWC	=	Naval Air Warfare Center
NC	=	numerical control
NEDALS	=	Naval Engineering Data Acquisition Locator System

NIPRNET	=	Internet Protocol Router Network
NSN	=	National Stock Number
OO-ALC	=	Ogden Air Logistics Center
P&IC	=	production scheduling and inventory control
PVE	=	process validation enterprise
PWA	=	printed-wiring assembly
R&D	=	research and development
RAMP	=	Rapid Acquisition of Manufactured Parts
REDARS	=	Reference Engineering Data Automated Retrieval System
RFQ	=	request for quotation
ROM	=	RAMP Order Manager
SAE	=	Society of Automotive Engineers
SAMMS	=	Standard Automated Material Management System
SATCOM	=	Satellite Communications
SCRA	=	South Carolina Research Authority
SDC	=	Seattle Distribution Center
SINCGARD	=	Single channel Ground and Air Radio System
SIPRNET	=	Secret Internet Protocol Router Network
SME	=	Society of Manufacturing Engineers
SMP	=	small mechanical part
SONIC	=	Sales Order Nonstop Inventory Control
SPARES	=	Spare Parts Production and Reprocurement Support
WVA	=	Watervliet Arsenal

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DoD seeks to reduce the cost and time required to procure replacement parts through flexible, computer-integrated manufacturing (FCIM). FCIM refers not to a single program or technology but rather to an amalgam of initiatives. Most of these initiatives have aimed at streamlining inventory management and engineering activities rather than at increasing production equipment capacity or capability. The technologies are sound, but, unfortunately, the military services have not done enough to understand where and in what order to implement them economically. Commercial strategies, such as those employed by Boeing, offer some alternatives that could be adapted by DoD.

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